Vol. 25, No. 4 *PSYCHOLOGICAL REVIEW PUBLICATIONS* April, 1928

Psychological Bulletin

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SENSATION AND PERCEPTION NUMBER
EDITED BY R. M. OGDEN

PUBLISHED MONTHLY
FOR THE AMERICAN PSYCHOLOGICAL ASSOCIATION
BY THE PSYCHOLOGICAL REVIEW COMPANY
372-374 BROADWAY, ALBANY, N. Y.
AND PRINCETON, N. J.

Entered as second-class matter at the post-office at Albany, N. Y., September 25, 1922

Psychological Review Publications
of the
American Psychological Association

PSYCHOLOGICAL REVIEW

containing original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 480 pages.

PSYCHOLOGICAL BULLETIN

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PSYCHOLOGICAL REVIEW COMPANY
PRINCETON, N. J.

Vol. 25, No. 4 April, 1928

THE PSYCHOLOGICAL BULLETIN

VISUAL SENSATIONS: A REVIEW OF THE LITERATURE FOR 1926 AND 1927 [1]

BY L. L. SLOAN
Bryn Mawr College

COLORIMETRY

The questions of color terminology, graphical representation of colors in the color solid, methods and instruments for color specification, and means of transforming data from one system of color specification to another continue to receive a great deal of attention. A few of the articles contributed present experimental data; for the most part, however, they are devoted to the theoretical aspects of the subject of colorimetry.

Kirschmann (**45**) writes briefly on color terminology. A committee of the Optical Society of America (**8**) presents a statistical report of the answers received in a widely circulated questionnaire on color terminology. The answers are grouped according to the occupation of the voter under the following headings: art and art education; industry; and research. The very marked disagreement in the use of terms emphasizes the need for a standard terminology. The voting showed a preference for the following terms, these terms themselves being sufficient to indicate the quantity designated: (a) light; (b-1) grays; (b-2) colors; (c) colors; (d) value or bright-

[1] Articles on color blindness are not included in this paper since these are reviewed in the BULLETIN at intervals by S. P. Hayes. Other topics *omitted* from this review are as follows: refraction; accommodation; muscle balance; pupillary phenomena; diseases of the eye; visual perceptions and illusions; descriptions of apparatus.

ness; (e) saturation or color intensity; (f) hue. The terms brightness and saturation were preferred by a majority of the research group, the terms value and color intensity by a majority of the other two groups. The results of this questionnaire were discussed at a meeting of the Optical Society of Great Britain (**27**).

Miescher (**54**) contributes a theoretical discussion of various systems of color specification and color measurement. Guild (**28**) contributes a paper entitled "A Critical Survey of Modern Developments in the Theory and Technique of Colorimetry and Allied Sciences." The various sections of the subject are dealt with in the following sequence: Properties of illuminants; spectrophotometry; the photometric properties of the eye (methods of heterochromatic photometry, visibility curve of spectrum, etc.); laws of color mixture (color geometry and color calculations); color measurement (various methods of colorimetry); standard conditions for colorimetry (field size, brightness and "white light"); standard terminology.

Schaefer (**68**) criticizes on experimental grounds Ostwald's use of the terms black-content and white-content in the specification of colors. He describes experiments showing that, when black is mixed with a color by combining black and colored sectors on rotating discs, the sensation obtained is equivalent to that which results from a decrease in the illumination of the colored surface. The composition of the light reflected is, moreover, identical in the two cases. To prove the first point, he increases the illumination on a surface formed by mixing a black and a colored disc until it matches the full color in a lower illumination. The second point is proved by comparing in a spectrophotometer the lights reflected from the two surfaces. By means of similar experiments he shows that adding a *white* sector produces a change in the composition of the light reflected from the rotating disc. Its effect cannot, therefore, be compensated for by decreasing the illumination. In answer to these criticisms Schollmayer (**70**) shows that the results obtained by Schaefer are not in conflict with Ostwald's use of the terms black-content and white-content. Ostwald has stated that the sensation produced by a reflecting surface does not depend on the absolute amount of reflected light but rather on the relative amount as compared with its surroundings. This statement, however, does not apply to conditions such as those used by Schaefer, where the two surfaces compared receive different intensities of illumination. Schollmayer emphasizes the fact that black-content may be introduced in other

ways than by the use of black sectors or black pigment. For example, when two illuminated fields are compared in the spectrophotometer and the amount of light in one field is made less than that in the other, since this field is relatively darker a black-content is introduced. The chief reasons for the misunderstandings in regard to the Ostwald theory, Schaefer claims, are due to the fact that the critics of the theory do not distinguish between colored substances and color sensations. Schaefer and Schollmayer differ also in their explanation of the action of the "Pomi," Ostwald's instrument for measuring the black- and white-contents and the hue of a color.

Flieder (**21**) also presents experimental data and a lengthy discussion pertaining to the differences between the concepts of black, gray, and white, and the concepts of lightness and darkness.

According to Bohnenberger (**10**), the following four principles have been used in spacing the colors in the color circle: distribution according to antagonistic colors, *Urfarben*, after-image colors, and equal difference of hue. These criteria lead to different results, no one of which may be said to be correct. For the purposes of practical color measurement, Bohnenberger believes the criterion of equal differences of sensation is probably the best, although an approximation to this criterion should prove satisfactory provided that the steps are constant and do not deviate too widely from equality. Weissenborn (**80**) attempts to determine experimentally whether the spacing of colors according to equal differences of sensation gives results which agree with the spacing according to antagonistic colors. His first problem is to determine whether the ten colors of the Prase-Baumann system differ by equal amounts of sensation. The samples of these colors given show that the ten hues are very unequal in saturation and brightness. The procedure consists in determining the size of the j.n.d. in hue at a number of points in the color-circle. By interpolation from these results the total number of j.n.d. steps between each of the ten colors is computed. The results indicate that the differences in sensation between the various colors are by no means equal. When the colors are respaced in the color-circle in such a way that equal distances along the circumference correspond to equal numbers of j.n.d. units, it is found that the complementary or antagonistic colors are not directly opposite one another. To explain this result Weissenborn suggests that either the two criteria do not lead to the same result or the discrepancy is due to the fact that the colors were not equal in saturation and brightness.

Although Oryng (**57**) agrees with Schrödinger that color is only

uniquely determined by specifying its complete spectral reflection curve, he believes that for the purpose of color comparison and for obtaining standards and norms some means must be had of transforming these data into other terms. In the method used by Kohlrausch the coördinates of the color in the color triangle are computed and from these data the hue, saturation, and brightness of the color are determined. Oryng objects to this procedure on theoretical grounds because of the uncertainty of the fundamental sensation data, and on experimental grounds because colors in the Ostwald system which have been shown to be complementaries do not prove to be so by these computations. These objections are perhaps avoided in Hübl's method of colorimetry in which the color to be measured is matched to a mixture of three standard primaries. Further investigations are necessary, Oryng believes, in order to decide whether or not Hübl's method is to be preferred to the Ostwald method.

Guild contributes three papers on methods and instruments of colorimetry. He criticizes (**29**) the monochromatic-plus-white method, contending that "from the practical standpoint of quantitative colorimetry, hue and saturation are not the fundamental elements of colour quality but must be regarded merely as derivatives of the trichromatic constitution of the colour. Practical and theoretical reasons are advanced to show that, whatever may be the advantage of specifying colour quality by hue and saturation, there are grave objections to practical methods of colorimetry involving the direct measurement of saturation." In a second paper (**30**) he describes a trichromatic colorimeter. "The instrument," he states, "is suitable for standardization work, as it may be employed to obtain the specification of any colour whatever in a form which may be converted if desired to any fundamental basis of specification. The three working primaries of the instrument are obtained by means of filters. The mixing of the primary colours is effected by a periscopic prism which rotates past three stationary sectors. Provision is made for adding any of the primaries to the colour under test, where this may be necessary in order to obtain a match. In this way colours of higher saturation than it is possible to match directly may be dealt with." A third article (**31**) "describes a new method of determining the quality of a colour, as defined by its position on the trichromatic colour chart, in which only the colour-matching properties of the eye are involved. The determinations depend on two colour matches in each of which the test colour is matched by a mixture in unknown

proportions of a standard colour and a monochromatic colour obtained spectroscopically, a different standard colour being used for the two matches. An instrument is described in which the method is embodied."

Raffe (**64**) points out the need for standards in the measurement of color in the industries, and recommends the Lovibond system for this purpose. Gamble (**22**) urges that the makers of colored printing inks agree on a common method of comparing the test patches of ink with the color to be matched. It should be possible, he believes, to arrive at some degree of standardization without employing elaborate apparatus, if a standard illumination, fixed distance of viewing, and standardized viewing filters are adopted.

In a review of previously stated laws of color and their applications, Runge (**66**) discusses the following topics: (a) the presentation of colors in the color triangle, (b) the methods used to establish the spectrum colors in this triangle, (c) the calculation of color coördinates from the spectral distribution of energy, (d) the relation of brightness to the problem of indication of color, (e) the calculation of brightness from the spectral distribution of energy and from color coördinates, and (f) color theory. Klughardt (**46**) also discusses the question of the location of colors in a color triangle.

Dziobek (**14**) explains a method of transforming colorimetric data from one trichromatic system to another, in which the center of gravity principle is used and the values of the three excitation coefficients are based on an equal energy spectrum, not on the "equal-proportions-giving-white" system. Priest (**61**) extends formulae previously presented to include the computation of the purity of non-spectral colors (purples). Judd (**43**) discusses the formulae proposed by Ives and by Priest for the computation of colorimetric purity from trichromatic coördinates, suggests still another formula, and compares the relative merits of these various formulae.

New experimental data on the proportions of three spectrum primaries required to match each wave-length in the spectrum are given by Tscherning and Larsen (**75**) for both normal and color-blind observers. Data are given for spectra of two different intensities whose ratios are 25:1. With decrease of intensity very marked changes occur in the proportions of the primaries required to match the various wave-lengths, especially those in the middle region of the spectrum. The bearing of the results on the Young-Helmholtz theory of color vision is considered.

PHOTOMETRY

Taylor (**72, 73**) investigates the possibility of obtaining valid data by the use of the flicker photometer under the conditions proposed by Ives. In compliance with these conditions the color sensitivity characteristics of each observer are first obtained by the use of yellow and blue test solutions, chosen so as to have equal transmission coefficients for light from a standard carbon lamp when compared in a flicker photometer by the normal or average eye. The color sensitivity characteristic of any given observer is obtained by having him determine by flicker photometry the ratio of the transmissions of the two solutions. Taylor finds that there is a straight-line relation when the ratios for a group of observers are plotted against their flicker photometer ratings in a given heterochromatic comparison. It is possible, therefore, to read off from the straight line the flicker photometer rating which would be obtained by an observer having a ratio of unity, *i.e.*, by an observer having normal or average color vision. Using this method, Taylor has determined the transmission coefficients of eight color filters of various hues and saturations. The transmissions of the same filters were also computed from spectrophotometric and standard visibility data. The average difference between the transmissions obtained by the Ives method and those obtained by computation from visibility data was 5.8 per cent. The greatest difference for any filter was 17 per cent and the least difference 0.5 per cent. There seems to be a systematic difference between the two methods since the flicker photometer in every case gives higher values for the blue, blue-green, and yellow-green filters and lower values for the red filters. The author believes, however, that the flicker photometer, when used under the conditions prescribed by Ives, gives results which are sufficiently reliable for all practical purposes.

The problem of a satisfactory method of making determinations in heterochromatic photometry is also attacked by Jouast and Waguet (**42**). They point out that the most frequently made photometric determinations consist in (a) comparisons of carbon lamps with tungsten lamps and with incandescent mantles and (b) comparisons of the various kinds of tungsten lamps with one another. In order to eliminate the individual differences which occur in the results of such comparisons, they suggest the use of filters in front of the eyepiece of the photometer which will absorb those wave-lengths for which the individual differences are greatest.

Filters were tried composed of varying proportions of cupric chloride, potassium dichromate and nitric acid in distilled water.

The photometric measurements made with the filter finally selected are not sufficiently extensive to warrant any definite conclusions. Determinations made by four observers indicate, however, that the use of the filter in comparing the different types of tungsten lamps decreases appreciably the variation between observers. The reading obtained with the filter had to be increased by 1.5 per cent in order to bring it into agreement with the average value obtained without a filter. When the same filter was used in comparing the light from a carbon lamp with that from a Welsbach mantle the individual differences in the readings of the several observers were not eliminated. The authors believe, however, that by choosing other proportions of the components it may be possible to find a satisfactory filter in this case also.

Walsh (**79**) has recently published a treatise on photometry which should prove of great value to those interested in this subject. It is illustrated throughout with many diagrams and charts. The several appendices at the end of the book give symbols and definitions of photometric quantities, tables of conversion factors, and other physical constants of use in photometry. An unusually complete bibliography is furnished at the end of each chapter. The total number of references given is several thousand.

COLOR AND BRIGHTNESS SENSITIVITY

Lippay (**49**) finds that the just noticeable difference in brightness is no greater with binocular than with monocular vision. The observations were made under light adaptation conditions with a stimulus field of 1 degree 46 minutes. The fact that previous investigators found an increase in brightness sensitivity with binocular vision is probably due, Lippay believes, to the use of stimuli whose retinal images extended beyond the fovea.

Priest (**62**) calls attention to a mistake which occurs in the second edition of Helmholtz's "*Physiologische Optik.*" In the presentation of Koenig and Brodhun's data on brightness sensitivity for monochromatic lights a typographical error occurs which results in an interchange of the references to the curves for long and short wave-lengths. The error has since been copied by Peddie and by Parsons.

Hulburt (**38**) suggests a possible explanation for the selectivity to wave-length of the achromatic response of the eye. He finds that when daylight is passed through 40 meters of water the resulting spectral intensity curve is very similar in shape to the visibility curve of the eye, although the latter is somewhat narrower. The maximum

of the visibility curve is at 560 mμ, approximately, when determined at high intensities by the light adapted eye, and is at 500 mμ, approximately, when determined at low intensities by the dark adapted eye. The maximum of the spectral intensity curve is in the neighborhood of 480 mμ and is, therefore, not far from that of the low intensity visibility curve. In the Prolerozoic and Paleozoic ages, when life was beginning on the earth, the earth was surrounded with water vapor. The suggestion is therefore made by Hulburt that the visibility curve of the eye owes its general characteristic to the spectral intensity curve of Paleozoic daylight.

Donath (**13**) used the j.n.d. method and the method of mean gradations to determine the relation between stimulus and sensation for tints shades, and saturation steps, *i.e.*, for mixtures of a chromatic color with white, black, and gray of the brightness of the color. When black or white was added the amount required to produce a j.n.d. in sensation was found to increase approximately in proportion to the brightness of the stimulus. When a gray of the brightness of the color was added, however, the amount of the neutral sector which had to be added was approximately constant. Results consistent with these were obtained in the experiments in which the observer selected the midpoint in sensation between a fully saturated color and black, white, or gray. In the first two cases the midpoint corresponded to the geometric mean between the brightnesses of the two stimuli; in the third case to the arithmetic mean between the purities.

Psychophysical data on the relationship between saturation and purity are also given by Jones and Lowry (**41**). These investigators have determined the number of just noticeably different steps in saturation between white and monochromatic light for eight wavelengths of the spectrum. The determinations were made with a constant field brightness of 12 apparent foot-candles. The change in purity necessary to produce a just noticeable change in saturation is greatest for stimuli having purities of from 40 to 50 per cent, and decreases with increase or decrease in the purity of the stimulus.

Rydin (**67**) finds that the ability to distinguish between green and blue-green decreases with the age of the observer. For this investigation a polarization anomaloscope was used which permitted the mixture and comparison of colors obtained from gelatine filters. Observations were made by ninety-two subjects between the ages of fifty-one and ninety-five years. Janicki and Lau (**40**) have investigated the change in hue which accompanies a change in the intensity of spectrum lights. By means of a spectroscope with a double prism

they determined the changes in wave-length necessary to maintain a constant hue as the intensity of the light was decreased. The results indicate that practically no change in wave-length is necessary to maintain constant the hue of the yellow region of the spectrum. In the other parts of the spectrum the wave-length must be shifted toward the yellow as the intensity is decreased.

ADAPTATION, AFTER IMAGES, AND CONTRAST

Achmatov (1) reports the results of a study of the changes in retinal sensitivity during a twenty-four-hour period of dark adaptation. Curves drawn from the data of a single set of observations show that retinal sensitivity, after the rapid rise of the first thirty to sixty minutes, increases intermittently with varying periods of very small gain in sensitivity. The curve plotted from the average data of six sets of observations shows, after the initial rise, a rectilinear relation between sensitivity and adaptation time. The sensitivity at the end of the twenty-four-hour period is approximately five times as great as the sensitivity at the end of one hour of dark adaptation. From the data there seems no reason to suppose that the maximum sensitivity is reached in twenty-four hours. The experimental data agree with the assumption that the process of dark adaptation consists of two monomolecular reactions, the second of which has a much smaller coefficient of reaction velocity than the first. Since, however, the assumption of two bimolecular reactions would also agree with the data, it is impossible to decide the order of the reactions from these experiments.

Möller (55) gives experimental data on the changes in retinal sensitivity which take place during the recovery from dark adaptation. The data show that there is a very rapid drop in sensitivity in the first few seconds, followed by a more gradual decrease in sensitivity.

Gellhorn (23) studies the effect on the chromatic threshold of previous stimulation of the eye. The stimulation is classified as direct when it acts on the eye whose threshold is determined, as indirect when it acts on the other eye. Pigment papers were used in conjunction with a Marbe-Zimmermann color variator to measure the thresholds. Pigment papers were also used as stimuli in producing the desired states of adaptation. In the earlier determinations of the threshold the procedure was as follows: The proportions of a pair of complementary colors were adjusted to give a neutral gray; the amount of one color was then varied at the expense of the other until the color was recognized by the observer. In later experiments

sectors of black, white, and a color were used, and the colored sector increased at the expense of the white until it could be recognized by the observer. The results obtained with direct adaptation are as follows: The threshold is raised after adaptation to the same color, and lowered after adaptation to the complementary color. The threshold is also raised when the eye is adapted to other colors; the threshold of red, for example, being raised as a result of adaptation to blue or to yellow. The effect of indirect adaptation is to raise the threshold in every case.

Similar experiments were later carried out by Gellhorn in collaboration with Fabian (**24**) for the purpose of determining the effect of adaptation on the size of the differential threshold or j.n.d. of brightness. The j.n.d. was measured as follows: Starting with 270 deg. of color and 90 deg. of white in the inner and outer fields of the color variator, the operator varied the proportions of the sectors of the inner field until the observer could just detect a difference in the brightness of the two fields. The results of these experiments may be briefly summarized. Direct adaptation to the *same* color increases the sensitivity (decreases the size of the j.n.d.). Direct adaptation to the complementary or to another color decreases the sensitivity. Indirect adaptation to any of the four colors produces a decrease in sensitivity.

Newhall and Dodge (**56**) investigate the possibility of obtaining negative after-images from stimuli which are kept below the limen of sensation by adaptation. Apparatus was devised by means of which it was possible to increase or decrease the saturation of the stimulus at a constant rate without producing a change in its brightness. The results obtained in this investigation were as follows: (1) Negative after-images usually did not result from unperceived color stimulation when the color stimulation was both introduced and withdrawn at the same rapid rate. (2) Negative after-images frequently resulted from unperceived color stimulation when the lack of color perception was a result of an adaptation attained by slowly increasing definitely subliminal stimulation, and the appearance of the after-images was favored by suddenly withdrawing the stimulus color. (3) The stimulus color could be perceived without corresponding negative after-images when the color stimulus was introduced rapidly and withdrawn slowly.

Gellhorn and Kühnlein (**25**) report quantitative determinations of the intensity of the negative after-image under various experimental conditions. The intensity of the after-image was measured

in terms of the saturation of the complementary color necessary to just cancel the color of the after-image. The following results were obtained: (1) An increase in the duration of the stimulus was found to increase the intensity of the after-image. (2) A change in the brightness of the background on which the stimulus was viewed produced a change in the intensity of the after-image. The effect of black, white and gray backgrounds were investigated. For yellow, green, and red stimuli the intensity of the after-image was found to increase with decrease in the brightness of the background. For a blue stimulus the reverse of this result was obtained. (3) The effects of stimulating a neighboring part of the retina with a chromatic stimulus were as follows: If the neighboring stimulus was very close and of the same color the intensity of the after-image was increased; if of the opposite color the intensity of the after-image was decreased. If the neighboring stimulus was farther away it produced a decrease in the intensity of the after-image in both cases. (4) The following effects were produced by direct and indirect adaptation. (For the meaning of these terms see page 209 of this review.) Direct adaptation to the same color increased the intensity of the after-image; direct adaptation to other colors decreased its intensity. Indirect adaptation decreased the intensity of the after-image in every case. (5) A comparison of these results with previously obtained data on the duration of after-images (Gellhorn and Weidling) shows that duration and intensity are influenced in the same direction by these various experimental factors.

Schjelderup-Ebbe (69) has used a method similar to the one just described, in order to determine quantitatively the relation between the saturation of the inducing field and the amount of color contrast induced. The amount of the inducing color needed in the contrast field in order to just cancel the induced color is taken as a measure of the strength of the contrast color. He finds by this method that the amount of contrast increases roughly in proportion to the saturation of the inducing field. The amount of contrast induced varies also with the hue of the inducing color. Purple, red, orange, and yellow induce less contrast than the colors in the other half of the spectrum. A supplementary investigation was made of the effect of the brightness of the contrast field on the amount of contrast induced. Contrary to the usual statement of the effect of brightness, it was found that the contrast was greatest when the contrast field was considerably darker than the inducing field. These experiments were tried only with a yellow inducing field.

A study is made by Grijns and de Haan (**26**) of the after-image and contrast colors obtained when colored reflecting surfaces illuminated by colored light are used as stimuli. They find that in all the cases examined the color of the after-image and the contrast constitute the remainder on subtracting from the color of the light the color in which the stimulus is seen.

Berry (**6**) studies the color changes in the after-image of a white light. He finds marked individual differences in the characteristics of the flight of colors in spite of the fact that the conditions of observations were the same for all of the twelve subjects tested. Many instances were noted in which the after-image oscillated between two colors. For a given individual the rate of alternation of the two colors was relatively constant.

The effects of varying periods of adaptation on the flight of colors are investigated and the following conclusions reached by Shuey (**71**): The length of adaptation influences the flight of colors qualitatively and quantitatively to a slight degree. With lengthened adaptation, the number of images containing yellow and red decreases, the number in which black occurs increases, the number of images that appear immediately decreases, the length of the image decreases, and the fluctuations become less numerous and less rapid. Adaptation apparently does not affect either the relative amount of movement or the absolute position of the image.

Judd (**44**) investigates the effect of the following variables on the Purkinje after-image: (1) brightness of stimulus, (2) hue of stimulus, (3) duration of stimulus, (4) state of adaptation of the eye. In order to explain the results of this and previous investigations, Judd suggests that some retinal structure close to the light sensitive layer gives off physical light about one-eighth of a second after the beginning of the stimulus.

PERIMETRY

Papers on perimetry are contributed by Ferree and Rand (17) and by the same authors in collaboration with Monroe (**18**). The first of these is a study of the effect of size of stimulus on the size and shape of the color fields. The fields were determined on the Ferree-Rand perimeter with standard colors under fixed conditions of illumination, background, and preëxposure of the eye. Five sizes of stimulus were used, subtending visual angles of 5, 2, 1, 0.5, and 0.17 deg. Three brightness values were used as preëxposure and surrounding field—a white, black, and a gray of the brightness of the

color at or near the limit of sensitivity. Size of stimulus was found to be second in importance only to intensity in determining the boundary of the field. In the case of red and blue, the 5 deg. stimulus carried the boundary of the color fields almost to that of the form field (field for a white stimulus on a black background). Size of stimulus produced the least effect with a preëxposure and surrounding field of the brightness of the color. The results are discussed in relation to the problem of diagnosing pathologic conditions of the eye. The second paper presents data on the form fields for 200 cases. The determinations were made with a stimulus subtending a visual angle of 1 deg. Its illumination at every point in the field was kept constant at 7 foot-candles. The purpose of the study was to determine the range of variation of the form field for the nonpathologic eye. The cases studied were sampled in order to include as many as possible of the outstanding variables which are not pathologic, such as age and condition of refraction. An examination of the results shows that there is only one case whose average breadth of field is less than 60 deg. In general the emmetropes and hyperopes have the wider fields, the myopes the narrower fields. A chart is given showing for myopes and for emmetropes and hyperopes the sizes of field which may be regarded as on the borderline between those for the normal and those for the pathologic eye. The results therefore furnish a diagnostic scale for use in the separation of pathologic from nonpathologic cases.

PERSISTENCE AND LAG OF SENSATION

Experimental data on the critical frequency of flicker and the theoretical implications of such data are presented in several papers. Allen (2) studies the so-called Porter effect over wide ranges of intensity of different monochromatic lights. In previous investigations by Porter, and by Ives, and more recently (1923) by Allen himself, it was found that when the reciprocals of the durations of flashes of light at the critical frequency of flicker were plotted against the logarithms of the intensities of light, the graph consisted of two straight lines of different slopes. When these "Porter-graphs" are determined for wider ranges of intensity than those previously investigated, Allen finds that instead of there being only two branches there are for many colors at least four or five. The previous explanation of the two branches as due to rod and cone vision therefore seems to be no longer adequate. The change in retinal sensitivity caused by fatiguing the eye with intensities of monochromatic light

corresponding to each branch of the Porter-graphs is next investigated. Some intensities of fatiguing light are found to produce an enhancement, others a depression of retinal sensitivity. The change in sensitivity is measured by determining the critical frequency throughout the spectrum before and after adaptation to the fatiguing light. The relation of the results to various other visual phenomena is discussed at length. Blair (**9**) continues the analysis of Allen's data on the Porter-graphs. He finds that the slopes of the different branches of a given Porter-graph are so related that they can be expressed as integral multiples of a common factor. This discovery is interpreted as indicating that the physiological effect measured by the critical frequency for any particular color is made up of equal elements which start off in groups from different intensity thresholds.

Data on the critical frequency of flicker are employed by Lasareff and by Polikarpoff to test the equations deduced from Lasareff's ionic theory of stimulation. Lasareff (**47, 48**) uses the results obtained by Schaternikoff and by Allen on the critical frequency of flicker at various intensities of light. He finds that one of the formulae derived from the ionic theory of stimulation gives agreement with both sets of experimental data. When the formula used by Allen to represent his own data is extended to include cases in which the state of adaptation is variable, Lasareff finds it to be in agreement also with the data of Schaternikoff. He concludes, therefore, that until further investigations are made it is not possible to decide between the extension of Allen's formula and the Lasareff formula. Polikarpoff (**60**), in order to test the Lasareff equations, obtained data on critical frequency, using as stimuli monochromatic lights taken from the green, yellow, and red regions of the spectrum. The intensities of these lights were measured in absolute terms by means of a thermopile. The critical frequency determinations were made at from four to six intensities with both central and peripheral vision. The data are found to agree with the various forms of the Lasareff equations within the limits of the accuracy of the determinations.

In connection with these papers on critical frequency there should be mentioned a very interesting article by Allen (**3**) which gives an historical account of the investigations relating to persistence of vision starting from the first known reference to the phenomenon made by Aristotle and including the work of Ives in 1912.

Vogelsang (**77, 78**) continues his investigations of the time elapsing between stimulus and response. The experimental method employed is based on the fact that when an illuminated slit is moved

across the field of vision there is a considerable displacement between its actual starting place and the place where it first appears. By measuring the magnitude of this displacement it is possible to determine the "sensation time" for vision. In these investigations the effects of the intensity and color of the stimulus and the rate of movement of the slit on the sensation time are studied. The problem has important applications to astronomical observations in which an observer has to detect the time at which a star moving across the field of a telescope reaches the central cross-hairs.

Herbst (**33**) considers from a theoretical point of view the relation between brightness sensitivity and intensity of stimulus, the phenomenon of lag of sensation, and the Purkinje phenomenon. The application of these three phenomena to the theory of the Pulfrich stereophotometer is discussed.

Holmes (**37**) measured simply sensory reaction times to red, yellow, green, blue, and white lights equated photometrically by means of a flicker photometer. Since no significant differences in the reaction-times to the different stimuli were noted, the author concludes that reaction-time is not a function of wave-length.

COLOR THEORY

The proceedings of two societies contain reports of papers read by Peddie (**58, 59**) in which mathematical analysis is applied to known data on color vision and new relations derived therefrom.

Venable (**76**) develops further his previously described quantum theory of visual sensations. Experimental data on hue sensitivity obtained by Jones are compared with the results of the theory. Irregularities in the hue sensitivity curve for an individual set of observations which would ordinarily be attributed to experimental error are claimed by Venable to be in agreement with the assumptions of this theory. His conclusions are summarized as follows: "(1) The same kind of mathematical law applies to energy levels in the visual purple as to energy levels in the normal spectrum of hydrogen. (2) The visual reactions take place in a substance associated with the nerve, which does not absorb light, and not in the visual purple, which is the light absorbing material. (3) The visual reactions are completely reversible, and absorb or liberate minute quanta of energy, all of the same magnitude. This is possible only in connection with readjustments of energy levels in the visual purple, and the function of light is to render such readjustments possible by bringing the visual purple to abnormal energy levels. (4) Although the nerve quanta

are all alike in magnitude, two, three, or six of them may be liberated or absorbed at the same time. To the number and direction of these synchronous discharges the quality of a color sensation is ascribable."

Meservey and Chaffee (**53**) report measurements of the electrical response of the retina in the following types of cold-blooded animals: lizards (horned toads and chameleons), turtles, alligators, and frogs. They find a *general* resemblance among the response curves of all the kinds of eyes examined. From a study of the differences in the responses obtained in the different types of eyes the authors draw the following conclusions: "Our results are in agreement with the common belief that cones are the chief instruments of vision at high intensities and rods at low intensities in that the intensities required to secure threshold or other responses are higher for the animals having cone retinas (turtles and lizards) than for those having mixed retinas (alligators and frogs), and in that the similarity of shape of the response curves is more noticeable with strong light, as if rods might be the determining factors at low and cones at high intensities. On the other hand we find about as much difference of threshold between the frog and the alligator as between the alligator and the turtle, and more difference between the horned toad and the turtle than between any other two, which looks as if the response might correlate fully as well with the habits of the animal as with the character of the retina. The normal habitat of the horned toad is in the blazing light of the southwestern plains, and it may well be that the animal, possessing the cone retina which is generally better adapted to high intensities of light and to the acuteness of vision which the horned toad exhibits in his pursuit of insects, has become specially adapted to these very high intensities."

Rich (**65**) discusses the relative merits as explanatory concepts of choosing gray and black as the constant process in vision. "A constant gray," he points out, "enables one to explain the facts of contrast, adaptation, after-image, etc., as applied to black and white by placing them upon the same basis as similar phenomena in color." "In all these respects the hypothesis of a constant black process meets difficulties."

Edridge-Green (**15**) reports the results of color matching equations made by 154 partially color-blind observers. He found that over 90 per cent of these observers "matched the normal equation either with the normal simple white or when the luminosity of the simple white was either reduced or increased." From this and other experimental evidence he shows that we are not justified in assuming

three underlying fundamental sensations from the fact that three colors can be mixed to give white.

Hiecke (**34**) shows that the results of König and Dieterici, who tried to determine the elementary sensation curves of the human eye on the basis of the Young-Helmholtz theory, may also be used to support a modified Hering theory. The difficulties involved in both the Helmholtz and the Hering theories are pointed out. As regards theories of nerve stimulation, Hiecke thinks that the facts suggest a photochemical rather than a photoelectrical explanation.

ACUITY

The effects of various experimental conditions on acuity and related eye functions are studied by a number of investigators with a view to determining the characteristics of illumination which result in the highest efficiency in the use of the eye. The forms of test used in these investigations were of various kinds. Acuity, brightness sensitivity, speed and accuracy in the performance of visual tasks in which acuity is a factor are some of the eye functions measured. By means of one or more of such tests the effects of intensity of illumination, quality of illumination, glare and other experimental conditions are investigated.

Atkins (**4**), in order to test the effect of various intensities of illumination on the efficiency of the eye, used a modified form of the Johns Hopkins number-work test. Each line of the test material consisted of 45 digits, each digit from 1 to 9 appearing five times. The subject was required to cross out the five ones, then the five twos, etc., until all the numbers of the first row were cancelled. This procedure was repeated with each of the succeeding rows. Since practically no errors were made, it was possible to rate the subject's efficiency in terms of the speed with which the task was performed. Five intensities of illumination were used ranging between 9 and 120 f.c. In order to investigate the effect of dark and light surroundings, at each intensity of illumination two series of tests were made in which the area surrounding the test-sheet was covered, respectively, with black cotton flannel and with white sheeting. In order to equalize the effect of practice, the series of ten tests carried out under each experimental condition were so distributed that each average score was influenced by approximately the same number of previous practice periods. With the black surroundings it was found that an illumination of 50 f.c. gave slightly greater efficiency than higher or lower illuminations. With the white surroundings no

significant differences in efficiency were produced by change of illumination. The author suggests, however, that with a smaller size of test-type an appreciable difference in efficiency with change in illumination might have been detected.

Banister, Hartridge, and Lythgoe (5) use as a test of acuity the number of mistakes made in the recognition of the letters of the alphabet. Two forms of test procedure were used: (1) prolonged exposures were given of letters subtending small visual angles; (2) short exposures, 0.019 sec., were given of letters subtending larger visual angles. Throughout the range of intensities investigated, 4.5 to 600 apparent foot-candles, the number of mistakes was found to decrease with increase of intensity. Similar tests made with a constant intensity of illumination and with a variable size of test-letter showed that increase in visual angle resulted likewise in a decrease in the number of mistakes. Of the two forms of test procedure, the method of short exposures proved the more practical because less fatiguing to the observer.

An investigation was made by Weston and Taylor (8) to determine the best value of illumination for the composing rooms of printing offices. Two compositors acted as observers. Their work consisted in the continuous setting of type for commercial directories. The output and the errors were measured for five intensities of artificial illumination ranging from 1.3 to 24.5 foot-candles obtained from the same system of lighting. Similar measurements were also made in daylight which varied in intensity between 21 and 495 foot-candles. The authors conclude that for the lighting system investigated there is an optimum value of illumination of 20 foot-candles.

Cobb (11) continues his investigations of the relations existing between the minimum time required to discriminate a simple test object, the visual angle subtended by the test object, the intensity of illumination, and the difference in coefficient of reflection of the test object and background. Data were obtained for the longer time of exposure than those previously investigated. In making the determinations the exposure was maintained constant and the intensity of illumination varied. The minimum intensity required to discriminate the test object was measured by the method of serial groups. Determinations were made with an unlimited exposure time, and with exposure times of 50, 100, and 200 σ. Four sizes of test object were used. The relative brightnesses of test object and background were 100:4 and 100:73. The results of these determinations show that when the

difficulty of discriminating the test object is increased, either by decreasing the contrast between object and background or by decreasing the size of the test object, a greater increase in brightness is needed to produce a given increase in speed. From the data obtained curves are plotted with speeds (reciprocals of the times of exposure) as ordinates and brightnesses of the background in logarithmic units as abscissæ. The plots corresponding to the various test objects may best be described as consisting of curves with a slight upward concavity, or as consisting of two straight lines of slightly different slopes, the greater slope corresponding to the higher brightness. The slopes of the lines and the point at which the slope changes differ for the different test objects. Similar data from a previous investigation obtained at a higher range of speeds and brightnesses, when plotted in the same way, form a curve whose concavity is downward. Since in all cases the change in slope is slight, Cobb concludes that speed of retinal impression may be considered approximately proportional to the logarithm of the brightness.

Cobb and Moss (**12**) report investigations of the effect on visual efficiency of requiring the observer to shift back and forth between fields differing in brightness. The task consisted in comparing pairs of letters for similarity. In the case of the higher brightnesses studied, a difference in brightness of the two fields was found to decrease the amount of work done. Thus brightnesses of 20 and 5 millilamberts were less favorable than equal brightnesses of 5 ml., brightnesses of 20 and 1 ml. less favorable than equal brightnesses of 1 ml. The favorable effect on acuity of an increase in the bright ness of one field was in these cases offset by the unfavorable effect of changing adaptation. In the lower ranges of brightness, however, this was not the case. Brightnesses of 5 and 1 ml. gave greater efficiency than equal brightnesses of 1 ml., and brightnesses of 1 and 0.05 ml. greater than equal brightnesses of 0.05 ml. showing that the actual level of brightness was the more important factor. In the same article data are given on the effect of a brightness contrast between the working area and the surrounding area. Two series of experiments were carried out. In the first the precision of setting a movable pointer was measured. The size of the working area was 1.0 by 0.75 deg. In the second the minimum time required to discriminate a black dot on a white background was measured. The working area was 5.8 by 5.2 deg. The substitution of dark surroundings for light led to an appreciable decrease in efficiency in the

case of the first series of experiments, but produced no significant change in efficiency in the second series.

Ferree and Rand (19) publish the results of extensive research on the effect of intensity of light on speed of vision. The minimum time of exposure required to discriminate the broken circle or International Test Object was determined for a wide range of experimental conditions. The test objects had coefficients of reflection of approximately 3 per cent and subtended visual angles of 1, 2, 3, 4.2, and 5.2 min. The coefficients of reflection of the background were 78, 29, 21, and 16 per cent. These four coefficients of reflection are approximately those of a white surface, polished brass or steel, unpolished brass or steel, and iron, respectively. The range of intensities investigated extended from 1.25 foot-candles to 100 foot-candles. In addition to the determinations of speed of vision under the experimental conditions stated above, supplementary investigations were made of the relation of size of pupil to intensity of light and speed of vision. These latter investigations consisted in (a) measurements of the actual size of the pupil corresponding to the various experimental conditions under which speed of vision had been studied, and (b) additional determinations of the relation between speed of vision and intensity of illumination with an artificial pupil. Some of the more important conclusions drawn from the results of this investigation are as follows: (1) Within the limits chosen for these experiments increase of size of object produces much greater increase in speed of discrimination than is produced either by change of intensity or by change in the reflection coefficient of the background. (2) In general the large effects of increase of intensity on the speed of discrimination occur in the lower part of the intensity scale. Their magnitude and the range over which they occur, however, are influenced very greatly by the size of the test object and the difference between its coefficient of reflection and that of the background. The smaller the object to be discriminated and the smaller the difference between its coefficient of reflection and that of the background, the greater is the need for high intensities of illumination, and the greater is the range over which an important increase in speed of discrimination may be expected from increase of intensity. Under all of the conditions tested, however, the benefit of increase of intensity is still present to a considerable degree at 100 f.c. (3) When speeds of discrimination are plotted as ordinates and the corresponding intensities of illumination in logarithmic units are plotted as abscissæ, the resulting curves consist of two approximately straight

lines of different slope. In some cases the slope is greater at low intensities, in other cases at high intensities. The intensity at which the slope changes likewise varies with the size of test object and the reflection coefficient of the background. The use of an artificial instead of a natural pupil does not give a simple logarithmic relation between speed and intensity of illumination. (4) The size of pupil is affected by other components of illumination besides the one coming from the object viewed. It is also affected by the size as well as the brightness of the illuminated area. From the measurements on the size of the natural pupil under various experimental conditions it is concluded that contraction of pupil is not an important factor in the comparatively slow rate of change of speed of discrimination with increase of intensity at the higher illuminations.

Hartridge, Lythgoe, and Matthews (**32**) investigate the effect on vision of replacing continuous by flickering illumination. The object of the study was to see whether an alternating current of a low periodicity produces an illumination which is less favorable to the eye than that produced by a direct current. The fluctuations in the current used in the experiments were sufficiently slow to produce a perceptible flicker. The efficiency of the eye was tested in a number of widely varied performances, such as perception of depth, perception of color and brightness, fatigue of pupil reflex, perception of movement, acuity, and speed of reading. In all but two of these performances equal efficiencies were obtained with the flickering and constant illuminations. In the tests for perception of movement it was found that continuous light permitted the movement to be seen with more peripheral vision than did flickering light. In the tests for speed of vision, one of the four observers read only 93 per cent as many letters in the flickering illumination as in the continuous illumination. For the other three observers, however, no significant differences in speed of reading were found.

Beyne and Worms (**7**) give data on the approximate visual acuity which may be expected in nocturnal illumination. The acuity determinations were made in an illumination of 0.0015 m.c., since this amount had been found equivalent to the intensity of illumination on a clear night without a moon in the month of September. Marked individual differences in acuity were found which did not correlate with the differences in acuity under ordinary intensities of illumination. The authors point out the importance of giving such tests to aviators and others who are required to work in low illuminations.

Irvine and Weymann (**39**) compare, for a number of observers,

the change in visual acuity produced by reading for 45 minutes with that produced by viewing motion pictures for 1½ hours. The Ives acuity test was used to make these comparisons. Reading was found to produce a greater diminution in acuity than viewing motion pictures. The ordinary black and white motion pictures resulted in a greater decrease in acuity than did the colored pictures produced by the Technicolor process.

Ferree and Rand (**20**) investigate the basis for the current belief that the mixture of artificial light with daylight is undesirable. In this study the following points were covered: (1) A comparison was made of the effect of artificial light, daylight, and mixtures of artificial light with daylight, on acuity, speed of vision, power to sustain acuity, and ocular fatigue. The results obtained indicate that there is nothing especially deleterious in the mixture of daylight and artificial light. When the tests are made at equal photometric intensities, the artificial light was found to give the poorest result, the daylight the best and the mixture of the two an intermediate result. (2) In a second series of experiments the artificial light was turned on at different times in the late afternoon on different days and the effect on speed of vision was determined. It was found from these experiments that a greater total intensity of light is needed during the late afternoon hours to give a satisfactory efficiency to the eye than is required at night or during the day in an inside room. This is attributed to the exposure of the eye to a high intensity of light during the day and to a rapidly decreasing intensity of light in the middle and late hours of the afternoon. The eye is not able to recover its sensitivity sufficiently rapidly to keep pace with the failing illumination; this lag in adaptation therefore results in a loss in visual efficiency. These conclusions are supported by the results of supplementary determinations of speed of vision with a fully adapted eye. It is suggested that, if artificial light of a sufficient intensity is added while the intensity of daylight is still high, the loss in visual efficiency due to the lag of adaptation can be decreased and the unpleasant effect of a sudden change in intensity and color of light can be minimized.

Priest (**63**) reports the case of an observer who stated that he could read for long periods by natural daylight without discomfort or serious after effects, but who was unable to read for half an hour by ordinary electric light without suffering great discomfort. An artificial daylight installation giving from three to four foot-candles likewise proved unsatisfactory to the observer, but when the intensity

of the illumination was increased to about 8 or 10 f.c. he was able to read with comfort and without bad after effects. When, however, an intensity of more than 10 f.c. from the ordinary incandescent lamp was tried the observer again found the results unsatisfactory. From these results and from a résumé of the previous data on the subject, both published and unpublished, Priest concludes that daylight, either natural or artificial, is to be preferred to incandescent light for reading purposes.

The problem of glare in lighting has been very extensively investigated by Holliday (**35**). The terms dazzle-glare and veiling-brightness are used to describe two varieties of glare which are of frequent occurrence. Dazzle-glare is the term applied to that class of phenomena associated with bright lights in the field of view which form images upon peripheral portions of the retina. Veiling-brightness is the more or less uniformly distributed flux of light from extraneous objects and sources shining into the eyes. The results of the investigation show that the least perceptible brightness difference between an object and its background increases directly with the illumination at the eye from the dazzle source, varies approximately inversely with the square of the angle which the glare source makes with the line of vision, and is practically independent of the brightness, size, type, distance, etc., of the dazzle source. The effect of a veiling brightness is found to be very similar to that of a dazzle source. In addition to the material summarized above, the paper also includes data on a number of other related problems. A second article by Holliday (**36**) considers the problem of ascertaining whether a given light source aids vision more by illuminating an object than it hinders vision by glare.

In the interests of a clarification of terminology, Luckiesh (**50**) considers briefly the causes and effects of glare and visibility, and the methods of their appraisal, and offers definitions for the various terms used in the discussion of this subject.

Luckiesh, Cobb, and Moss (**51**) present the results of a series of three-minute tests which were carried on as a check on the reliability of the so-called "li" test as a means of drawing important conclusions as to the value of various factors in lighting. In an appended reply Ferree and Rand, the originators of the test, show that in their experiments these investigators had failed to control the important variables (progressive fatigue, progressive adaptation, and practice) and had neglected to take other precautions all of which had been fully

described in print and discussed as being essential to the successful employment of the test.

Tscherning (74) describes his own apparatus, method and procedure for the objective measurement of clearness of vision.

Lythgoe (52) contributes a brief summary of research on visual capacities in relation to illumination carried out during and since 1914. After a short introduction dealing with definitions, the works considered are dealt with under the following headings: influence of different intensities of illumination on visual acuity; discrimination of shapes and brightness differences; adaptation as a factor in visual discrimination; influence of lateral illumination, including "glare," on visual judgments; speed of retinal impression; influence of illumination on color discrimination; visual fatigue; and methods and apparatus. Full references are made throughout to the original works considered.

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FACTS AND THEORIES OF AUDITION

BY CHRISTIAN A. RUCKMICK
University of Iowa

The contributions to this field since the last summary was published (**54**) still follow the previous trend. There are a number of discussions of auditory theory on the one hand and, on the other, a large number of experimental investigations which directly or indirectly fortify the theoretical points of view assumed in the studies. In addition there are facts which appertain to the higher mental processes, including musical appreciation. In the present summary the compiler has attempted to include the more important theoretical and experimental researches in this rather broad field, realizing that many contributions have been either purposely omitted, for the reason that available space must be given to more typical and critical studies, or they have been unintentionally overlooked since many periodicals are not available to the compiler at this time. The *Psychological Abstracts*, however, have brought some of these articles to the notice of the writer, and they have been outlined wherever their bearing on the subject in hand was pertinent. This study serves as a means of general orientation in the subject, with the possibility of inducing any reader who wishes further enlightenment to consult the original publications. If there have been any serious omissions the author is quite willing to have them brought to his attention.

Theory of audition. Again the Young-Helmholtz theory, commonly known as the most important resonance theory, has found stout defenders. In reply to Boring's proposal of a theory that requires a central analysis of sound, Wilkinson (**62**) brings forward several very important arguments. His attitude in regard to the "all or none" doctrine of nerve impulses, which partly led Boring to give up the resonance theory, is that this theory is not an insuperable barrier to such a resonance theory. He shows that on well established grounds the basilar membrane might still respond sympathetically to individual tones. Also in terms of the refractory period Boring's hypothesis seems to be seriously undermined. The writer points out four positive bits of evidence in support of the resonance theory. As indicated in a previous summary, (**52**) Hartridge believes

that the length, tension, and mass of the basilar fibers show a regular gradation that is adequate to a mechanism responding on the principle of sympathetic resonance. This point Wilkinson again emphasizes. Secondly, the mutilation of the organ of Corti at different levels produced in a number of controlled cases a corresponding insensitivity to pitch. Thirdly, functional damage to the organ of hearing through occupational deafness shows a regional disability; and, fourthly, the direct evidence of adaptation which affects pitches within 8 d.v. of the tone to which the ear has previously been adapted.

In much the same way Banister (4) seriously criticizes Boring's theory of central analysis, making two preliminary comments. First, a very doubtful system of physics advanced by Köhler is made the basis of hypotheses that are far too broad; and, secondly, a claim that the resonance theory fails to prove the experimental data at hand is not fully substantiated. Banister emphasizes these criticisms by referring to Hartridge's work in the field of intensity where the latter investigator applied the "all or none" principle to the resonance theory. Banister shows that many of the facts of sound localization do not fit Boring's plan of analysis.

Gundlach (29) gives Boring credit for bringing together certain facts in connection with auditory phenomena, but brings into play some additional facts that cannot be explained by the Boring theory. The summation of intensities is not of the type demanded by the theory. Again, he believes that intensity and volume are somehow confused in this theory, although not consistently so. Gundlach's third criticism questions the applicability of the theory to monaural localization of sound. In this case the theory of overlapping cortical areas would require amendment. Finally, Banister's work is cited in substantiation of the reduction of phase-differences to differences in time, and it is claimed that Boring has overlooked the brightness attribute of tones.

Another investigation that appears to be favorable to a theory of sympathetic resonance based upon the stimulation of the structures that are attached to the basilar fibers is that of Polyak (**51**). In this histological examination of the auditory nerve paths in bats, mice, rats, cats and in human fetuses less than seven months old, through methods of proper staining it was established that the nerve fibers run intact from the spiral ganglia to the primary auditory bulbar center. In general the cochlea fibers retain their original stratification. This author has also gone more elaborately into his contention re-

garding the function of the basilar fibers in the Bekhterev fortieth anniversary commemorative volume (50) where he claims that structurally the separate auditory fibers become more and more distinct as they approach the basilar membrane. Incidentally, in another study of the human fetus, the Forbeses (25) indicate that a jump of the fetus was discovered thirty-one days before birth immediately after the production of a sound at some distance away. The author does not believe that the stimulation was due to mechanically conducted shock, but that there was some evidence for receiving the sound through auditory vibration.

In many respects the most fantastic theory recently proposed is that by Doniselli (19) who proposes to make the cochlea a spatial organ similar to the labyrinth. Its position as a tri-dimensional system together with its spiral construction gives him sufficient courage to refer to it all sorts of musical tasks, to say nothing of mathematical ones. In the latter construction, its structure is found to be identical with the Cartesian logarithmic spiral. Functioning on the principle of this spiral it analyzes sounds and perceives harmony directly. In only a very general way is this theory to be connected with that of Ewald who portrayed acoustic images analogous to retinal images.

Our general survey for the last few years indicates, therefore, the inherent tenacity and adequacy of some modified form of the Helmholtz theory. One must not forget the tremendous advances made in neurological theory, on the one hand, and the accumulated facts in audition on the other. But most of the workers in both fields are agreed that with slight changes, such as the spreading out of the vibrating effect over several basilar fibers, and the stimulation of the hair cells through the tectorial membrane, the Helmholtz theory still holds good. Perhaps with these modifications the Helmholtz theory is hardly recognizable; but certainly the work on sound localization together with the "all or none" principle has not seriously undermined the possibility of some resonant theory.

Auditory sensations. The most significant features in this field lie in the direction of further study concerning moot points. Since Bishop's investigation of the auditory after-image, we have been surprised at the failure of an auditory after-image to appear. But Kucharski (39) by another method discovers that with 100 interruptions per second of a sound vibrating at 200 d.v. the discontinuity is directly perceived. With 500 interruptions per second of 1,000 d.v.,

roughness is sensed. This would indicate that the positive after-image does not last long enough in either of these instances to cover the break, as it does in the case of visual stimuli. Pattie (**48**) has likewise made an experimental study of adaptation with an audio-frequency oscillator. Through exhaustive study with tones ranging from 256 to 4,096 d.v. the results show that there was a definite decrease in intensity of tone due to what the author calls " fatigue." The question of the duration of this fatigue has not been satisfactorily worked out due to the paucity of judgments. On the other hand, as propounders of new theories will have to note, there was no exception to the fact that fatigue of a tone at a given frequency affects the intensity of all tones which were used in the experiment. But, as the author points out, the explanation need not apply specifically to the sensory mechanism since the locus of fatigue is at present unknown. Less fatigue is produced by a weak tone than by a strong one and the recovery is quicker for the weak tone. With some exceptions the longer period of stimulation gives the greater fatigue. The fatigue effect persists when variable factors among the higher mental processes, such as attention, are under control.

Bondarenko (**10**) has attempted to get at the phenomenon of adaptation or fatigue, as it is quite commonly called, by mounting an adjustable coil attached to a telephone receiver between two oscillating fields. After tests for auditory acuity, he subjected the observers to stimulation of from three to five minutes' duration near one of the primary fields. He then plotted the individual curves which illustrate recovery from effect and give a means for diagnosing pathological situations. Salman (**55**) has also investigated adaptation and he finds that there is a rise in the threshold of very low tones, but also of very high tones.

Banister (**2**) has gone into the matter of the transmission of sound through the head and believes that the evidence so far obtained is untrustworthy. In some brief experiments of his own he has found negative results. Valentine (**61**), in a note on the binaural beat, questions the perception of the phantom sounds under the conditions outlined by Stewart in a previous study. When the two tones differ by one d.v., the beat is more pronounced than the phantom sound movement. With a smaller difference of pitch the phantom movement predominates. With a partial mixture of two sound trains he obtains a monaural as well as a binaural beat. In fact, during a long series of experiments with tones registering from 1 to 70 beats per

second, phantom movements were found very rarely. In a parallel column he juxtaposes his results with those of Stewart and finds discrepancies at almost every point.

The work on vowels has gone in two separate directions. One study by Engelhardt and Gehrcke (**21**) follows the lead of a vowel-tone analysis made under the direction of Köhler, whose work in this field is already widely known. With the use of the Trendelenberg vocal curves, shields were interposed between a source of light and a well standardized photo-electric cell. While there were only two observers, *U* (all vowels are given the German pronunciation) was plainly audible at 125 to 176 d.v.; *O* at 250 to 352 d.v.; *A* at 705 to 1,000 d.v.; *E* at 1,410 to 2,000 d.v.; *I* at 2,820 to 4,000 d.v.; while at 8,000 d.v. the vowel quality disappeared. In some additional experiments arrangements were made to duplicate phase differences in terms of these curved shields, but the author discovered that phase differences would not influence the clang quality of the tone. There were also some experiments made with simple words formed by means of vowel sounds and consonants. Another study, by Crandall (**14**), obtained oscillographic records of a number of characteristic vowels. These records show that a double peak occurs almost invariably in the frequency spectra of vowel tones. Accordingly, a double resonator system of production was followed in which the best results were obtained with the *A* sound, as in "father," and only fair results with *O*, *I* and *E*. By means of a rubber tube 15 inches in length the author obtained additional data which indicate that the windpipe has probably some function in fixing the lower frequencies. In general, the physical features of the mouth and pharynx were roughly reproduced. Crandall (**13**) has also recently written a volume on the theory of vibrating systems and sound which furnishes a large amount of material supplementary to treatises on sound radiation, transmission of sound and architectural acoustics. Liddell (**42**) has issued a third bulletin in which he studies the energy-frequency ratios of diphthongs and, by means of a graphic method, proposes the substitution of these ratios as indices of vowel-tone qualities to replace the classifications of traditional phonetics. A diphthong emerges as "a speech tone whose quality constant shifts from one part of the spectrum to another through one or more intervening bands." In a preliminary experiment Pickford (**49**) has tried to determine the effect of visual stimulation on the lower auditory limen for intensity, by means of a three-sided screen and overhead

illumination with red-orange, blue and yellow lights. He obtained judgments at subliminal, liminal and fully audible intensity with a tone of 384 d.v. produced by the Banister oscillating circuit. There were no definite results and the technique was quite inadequate.

Kingsbury (**36**) has studied the intensities of pure tones ranging from 60 to 4,000 d.v. with regard to the Weber-Fechner law. With 22 observers, of which 11 were men and 11 women, it was discovered that when the amplitudes were increased in equal ratios the loudness of low tones increased much more rapidly than that of high frequencies. Above 700 d.v. the rate was nearly uniform. Some significant investigations on hearing through the sense organs of touch and vibration have been followed by Gault (**26**) under the auspices of the National Research Council. An unusual capacity for refinement of discrimination within the realm of the cutaneous and vibratory senses has been demonstrated. Both vowel qualities and musical selections were enjoyed by means of the thumb resting on the diaphragm of a single-unit telephone receiver. The experimenter himself became somewhat adept in learning to read vibrations in this way. An apparatus was finally constructed, known as the "teletactor," by means of which, with four fingers on one side and the thumb on the other, sensations were obtained for a thorough enjoyment of speech sounds.

Stone (**59**) has measured the latent time for auditory tactual complications. This is equivalent to about 50σ in favor of the stimulus to which the observer is predisposed. He concludes, therefore, that this advance in time is not an artifact. Travis (**60**) has noted the distracting effect of mental tasks, such as mathematical problems, memorization of poetry and the reading of prose, on the stimulus limen for a tone of constant pitch. In general there is a surprising decrease in the limen for all sensory intensities. In other words, he claims the possibility of a heightened acuity due to a generalized effect. This has some very significant applications to the general intelligence factor advocated by Spearman, and is against the traditional assumption in the field of attention.

A considerable amount of work has been done in connection with the problem of hearing among the lower animals. The most elaborate study is that of Kuroda (**40**). The effect of the ringing of bells on the respiratory mechanism was carefully noted and there were also experimental histopathological investigations in which very loud explosive sounds were made, such as the firing of a pistol. Afterwards

the auditory apparatus was investigated. Study of the reactions of a large number of amphibians, including 16 tortoises, 19 snakes, 35 lizards, a large number of frogs and newts, and finally a variety of fish, indicated no auditory response in fish, a definite response in lizards, but not so clear a response in frogs and toads. He concludes that auditory sensations are found among lizards, adult frogs and toads. In another study (**41**) the same author conditioned the feeding response of tortoises to the sound of a bell. When the sound of the bell was given together with an electric shock the auditory stimulus was later found to be completely effective in restraining feeding. Auditory phenomena have also been studied in decerebrate cats by Forbes, Miller and O'Connor (**24**). The brainstems of these animals were connected to a Hindle string galvanometer. Abrupt sounds produced marked deflection of the instrument, while tuning forks give only a very feeble result. Some bearings of this study on auditory theory are offered for consideration. Eggers (**20**) concluded from the flying reaction of moths that auditory sensations exist also in this species, although moths react more violently while flying up than while passively resting.

Held and Kleinknecht (**33**) have performed a most pertinent operation by artificially producing tonal gaps in the ears of guinea pigs by drilling into the cochlea at various regions. While the tension of basilar fibers in these regions was released, it is claimed that no injury was done to the organ of Corti at these respective places. As a result the authors noted that the ear-muscle reflex to certain pitches was absent after the operation, which beyond doubt is analogous to certain cases of tonal gaps produced by degeneration of the basilar fibers. As a result it is argued that the Helmholtz theory is more satisfactory than that of Ewald.

The only discordant note against the Helmholtz theory is that of Goebel (**27**) who led tones from a tuning fork, which was set against the bones of the head, at the same time to one of the ears. No interference phenomena were produced although a lowering of the tone occurred. When the wave difference produced by this method amounted to $\frac{1}{2}\lambda$, C was lowered to F, then C_2 to F_1. When the difference amounted to $\frac{1}{4}\lambda$ the tone was lowered an additional whole tone. Goebel cannot understand how a theory involving resonance vibrations can account for these phenomena. Dodge and Loutit (**18**) have recorded, by means of four different devices attached to the guinea pig, the bodily movements that are made in response to a noise.

A record was obtained through the use of the Dodge pendulum photochronograph. The bodily movements begin 30 σ after the noise is started. The starting reflex decreases in amplitude after repeated stimulation. The relative refractory period is 500 σ. The ear reflex is clonic and it is hoped that the refractory period will provide a key to the lasting effects of the composite reflex to recurrent stimulation.

Sound localization. In comparison with our last report there have been relatively few publications on sound localization. Banister (3) has continued his notable work in this field and again attacks the data obtained by Myers and Wilson. According to their results the total intensity of sound affecting both ears should vary as the relative phases impinging at the two ears are altered. His data seemed to show that this difference, as calculated from their results, was too small to be appreciated although a change of 10 per cent of the total intensity of sound is easily recognized. In general, he seems convinced that the Myers-Wilson hypothesis of localization, by recognition of phase differences through their intensive differences, or summation of energy, is untenable.

Bennett (9) by means of the single impulse technique finds that two tones can be localized with absolute certainty when they are presented separately to the two ears at a difference of 1 σ. In other cases this value was reduced to .1 σ but fatigue quickly enters at this point. Right and left localization was obtained in this way. From the work of Trimble in our own laboratory, not yet published, our observers made no errors of localization when there was a separation of .42 σ, while there was a fair degree of certainty for the region of .32–.40 σ.

One of the most noteworthy contributions to the field of sound localization during the year has been made by Halverson (30). Although previous workers had found considerable difficulty in the localization of very high tones, he found definite evidence for such localization as high as 18,000 d.v. Some of his observers could not reach this point. He claims, however, that changes of phase in tones of high frequency produce movement over a more limited area than do lower tones and that median localization is difficult above 3,000 d.v. His apparatus consisted of an electrically driven audio-oscillating fork, elsewhere described in this article, for the low tones, and a phosphor-bronze ribbon magnetically driven for high tones. These sources were enclosed in a sound-proof box with a T-tube to the ear of the observer.

A resurrection of the Münsterberg and kindred motor theories of sound localization is suggested in the work of Goldstein and Rosenthal-Veit (**28**) who have discovered that fewer errors in localization are made by those who have no visual imagery, or who repress their visual images, than by those who use this auxiliary means of localization. The best cue appears to be a direct acoustic motor coördination. This is proved both directly by comparison of data from the various types of observers, and also indirectly through a controlled series in which it was found that when the eyes are turned toward the left as the stimulus is sounded there is an error to the right. Furthermore, in pathological cases of oculo-motor imbalance or paralysis the same errors are discovered. Of course we cannot infer visual images from these latter results but only a motor disturbance.

The reviewer is struck at once with certain suggestions that have come from his own research (**53**) in connection with a comparison of two traditional methds of sound localization: the method of calling off localizations with reference to a visualized chart, and the method of pointing to the direction from which the sound is perceived as coming. In this study our results show that the method of pointing with its close auditory motor coördination is slightly more reliable, although it is more difficult to record and is sometimes translated into visual terms.

Apparatus. A considerable amount of work has been done on determining the constants of error in connection with organ pipes. Anderson and Ostensen (**1**) have studied the effect of frequency on the correction for the ends of the pipes. When such organ pipes are used as generators of complex tones there is a limit to the number of partials that are affected. The true values in some cases are sharp for the higher proper tones, but generally the true tone is flatter than those calculated from the series. Among other factors which influence both the frequency and the number of partials are the materials of the walls and the size and shape of the mouth of the pipe. Barus (**5, 6, 7, 8**), whose work was quoted extensively in one of our early summaries (**52**), has continued his pinhole probe experiments and has developed a very significant technique involving mathematical calculations for testing out the pressure at various points within massive air columns. The pinhole probe is mounted on a long quill tube and connected with an interferometer and a U-gage. The displacement of this gage by the pressure within the column can be very accurately observed. Barus has worked with broad and slender

horns 40 cm. long, and with narrow tubes. Higgs and Tyte (34) have also considered the affect of various flange systems on the open-end correction but in this case in connection with the square organ pipes. They indicate that the problem is important because from a physical point of view the stimuli are transformed at the flange from plain auditory waves into spherical ones. Open-end correction for this form of pipe is found to be nearly adequate for the "hopper" type of flange. From their discussion Higgs and Tyte conclude that the acoustical and electrical problems involved bear a linear relation to each other. Paris (47) has studied the relation between organ pipes which are stopped with various types of absorbing material. In a technical mathematical treatment the theory of absorption of sound energy is discussed, and the conditions for complete absorption are outlined. From another angle Mason (43) has described the absorbing characteristics of tubes used as acoustic filters when run off to the side of the main channel of conduction in a manner similar to the usual placement of interference tubes. His calculations indicate a corroboration of the Helmholtz-Kirchoff law.

By means of a very ingenius device D'Albe (15) has been able to produce acoustic spectra. He uses a series of highly selective resonators confronted with vibrating reeds which bear very small mirrors. From these the beams of light are focused in such a way that a complete photographic record of sound can be made as regards intensity, pitch, and duration. With an extension of the series of all possible pitch ranges, the apparatus ought to lend itself easily to the photographing of timbre but in any event the inherent inertia of the reeds and their vibratory systems must be taken into account. Other workers have continued to investigate the transmission and reflection of sound through partitions made of various materials. Davis and Littler (16) have used the Watson method with felt of various kinds. No appreciable reflex effect was found to occur with regard to the source of sound although pitch ranges from 250 d.v. to 1,600 d.v. were used. This work compares favorably with Sabine's method of reverberation. Heimburger (32) used a different technique than the Taylor method with the customary Rayleigh disk. By this method the absorbing material is put in the end of the cylindrical chamber.

Knudsen (38) has continued to investigate the hearing qualities auditoriums and the effects of noise and reverberation. He finds that if the syllabic articulation is only 65 per cent effective the acoustic conditions are just barely acceptable. 75 per cent corre-

sponds to a satisfactory condition when one listens attentively, and 85 per cent or more gives an entirely satisfactory solution. He enumerates some of his interference tests and reviews the conclusions formerly held. The interfering effect, of course, increases directly with the increasing loudness of either tones or noises, and is more effective in the case of consonants than with vowels. Noises are more effective as interferences than an equally loud tone of any pitch. The author reiterates, finally, that reverberation is probably the most important factor in determining the acoustics of an auditorium, as W. C. Sabine and others have so effectively shown.

Fernberger (**23**) has suggested an improvement in the method of actuating tonal cylinders of the Koenig type by magnetically releasing a steel ball which is thus dropped on the cylinders. The impact is kept constant. Boring (**11**) gives some very useful data together with a method of making and calibrating the Koenig cylinders. The formula for this calculation is provided on the assumption that the steel bar from which these cylinders are cut is of uniform density. Stewart (**58**) has outlined an apparatus and procedure for the direct absolute measurement of acoustic impedance through the effect of a branch line on the main transmitting line. This value can be obtained. It is equal to the ratio of pressure to the volume of the current. McGinnis (**44**) briefly describes a method of electrically controlling telephonic sounds for use in the method of constant stimuli. A rheostat switch with a suitable number of contact points controls the variable which is, then, automatically and periodically given in alternation with the standard through a metronome equipped with a mercury contact. Klein and Rouse (**37**) have reviewed the methods of continuously exciting and of calibrating tuning forks. Six methods are given for approximate calibration and four for precise calibration. An extensive bibliography is supplied.

Halverson (**31**) has suggested for acoustical work a special circuit by means of which a tuning fork of 1,000 d.v. is incorporated in an amplifying circuit which will give an approximately pure tonal effect. The usual interrupting spark of the fork is replaced by a carbon capsule.

Psychology of music. This field embraces a rather extensive series of investigations, some of which have bearings on other sections of this review. A few books should be mentioned here. Howes (**35**) in affiliating music and psychology has written on the gregarious instinct found in the audience and manifested by performers. He

makes some general comments on the emotions represented in music, on the rhythmical factors, and he gives a psychological analysis of applause. The influence of the subconscious and the matter of musical appreciation are also discussed. Diserens (17) gives a rather complete account of the various types of reaction to music among human subjects as well as among the lower animals. Even the influence of music on sickness and on work is considered. The book is replete with historical data from myth and magic to an historical survey of experimental work. The results of experimental investigations are reported in a separate chapter. An extensive bibliography is included. Diserens summarizes his data in the statement that "the agreement of the accounts from so many sources yields a convergent proof of the reality and nature of the phenomena." The effect on involuntary responses suggested experimental work on voluntary reactions.

Under the title of the *Effects of Music* Schoen (56) has collected and edited a number of essays which were recently in competition for the Edison prize. Each chapter consists of a separate study by individual investigators among which are some of the outstanding contributors to the field of the psychology of music. The various types of listeners have been studied and the source and effect of musical enjoyment on the side of imagery, mood, organic and kinaesthetic factors have been experimentally analyzed and discussed. The prize-winning essay by Washburn, Child and Abel, "The Effects of Immediate Repetition on the Pleasantness or Unpleasantness of Music," reveals the interesting fact that pleasantness is lost more quickly for those who are musically inclined than for the unmusical listeners. Pleasantness was continued on repetition if attention could turn to various musical factors within the composition with which the listener had not yet become familiar, whereas fatigue would set in when the individual found nothing more to which to attend.

The subject of consonance still receives attention. Brues (12) devised certain non-musical intervals, each one of which was the geometrical mean between two of the musical intervals. These were located at pitches of 150, 250, etc., "cents" on the basis of the Helmholtzian calculation. By the method of paired comparisons, using "unitariness" as a criterion, he finds that the Stumpfian hierarchy is overthrown. Nothing sacred remains about the inherent fusion of the accepted musical intervals. The octave still heads the list but the fifth is subordinated to no less than four of the traditionally "dissonant" intervals. "Roughness," due for the most part to

beats and difference tones, is the most permanent factor in making decisions, while pleasantness is not a criterion at all, but a result. In some cases musical factors tend to disturb the judgment when allowed to enter into the criterion. According to this writer fusion is still, as v. Ehrenfels first supposed it to be, a typical illustration of "formal" relationship.

Metfessel (45) has distinguished clangs, as simultaneous fusions of partials, from sonance, which applies to successive fusions either in the combination of individual vocal traits and vowel changes or, in the most typical instance, of the vibrato. When this distinction is carried to its logical conclusion it would be significant to ask at what point the successive fusion, or sonance, becomes the perception of melody.

The influence of special stimuli, such as noises and musical tones, upon the so-called associative reflex, was determined by Shnirman (57) who discovered that noises lasting from five to ten seconds have a stimulating effect in connection with visual stimuli, whereas musical tones have a restraining effect. The major triad has a greater restraining effect than the minor. There are marked individual differences and further experiments are needed, especially in view of the fact that the distraction may be largely a question of attention in the form of *Aufgabe* or attitude.

In a very extensive article which summarizes the historical materials, Mull (46) has again gone over the question of the acquisition of absolute-pitch consciousness. She is quite definite in her conclusion, which is contrary to the traditional results, that with adequate training and a proper phenomenal attitude this ability can be acquired permanently. She finds no objective or introspective evidence for the recurrence of tonality in successive octaves although a number of octave confusions occur in her results.

Farnsworth (22) has improved upon the technique of Max Meyer in determining the value of melodic endings, but he still leaves much to be done since it is difficult to obtain a melodic perception out of only three successive notes. He finds, however, that a note with the ratio of 3, where 2 represents a return to the tonic, is better than an ending with a ratio of 5, and that the ratio of 5 is better than the ratio of 7 as an ending. In both of these cases, however, the preference is small. When the ratio of 3 is compared with that of 7 there is much greater preference for 3. He discovered no sex differences in this regard.

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APPARENT MOVEMENT

BY PAUL C. SQUIRES
University of Vermont

The present review deals with the very recent literature on apparent visual, tactual, and auditory movement. DeSilva (3) has made an experimental investigation of some of the determinants of apparent visual movement. Attention was principally devoted to the influence of form of stimulus, character of the background, meaningfulness of stimulus, position, encompassment of stimulus, fixation point, repetition, fatigue, and predispositions of various orders. The instrument used was a three-phase modification of the Dodge tachistoscope. The time interval between exposures was sixty sigma throughout all the experimental series, while the first and second stimuli were each exposed for a period of sixty-five sigma. The *Zwischenzeit* was illuminated. There were three regular observers; eleven casual observers contributed one hour apiece. DeSilva shows that the sharpest and clearest movement is obtained by using a white figure on a black ground. The most effective point for fixation is a peripheral position at or near the completion of rotary movement. Good movement is favored by an increase in the complexity of the stimulus pattern. Solid crochet threads as stimulus objects give better results than do mere representations in ink. When lines are thickened at the ends, as in the case of the windmill figure, movement is evoked more easily and definitely than when the lines are of uniform thickness throughout their entire extents. Perception of movement is assisted by surrounding the stimulus field with a line. A distinctly meaningful, animate pattern occasions a clearer movement than does a pattern possessed of a lower meaning level, and of an inanimate character. In an equivocal situation the so-called "splitting" movement sometimes occurred. This type of movement is presumed to correspond to the "pure phi" of Wertheimer. It is suggested that this splitting movement be classified as a separate species of movement. Repetition at first improves the movement pattern, but with the onset of fatigue the pattern decays. DeSilva has examined the grounds of the so-called directional tendency. The directional tendency may be partly interpreted in terms of the stimulus setting.

Concerning those determinants not inherent in the stimulus complex, it was found that after the development of a synthetic attitude a passive attitude leads to improvement of the movement experience, while an active set manifests the tendency to merge into an analytic attitude with the consequence that the perception of movement passes over into that of succession. Rotary movement from the vertical position is initiated with greater ease in a counter-clockwise than in a clockwise direction; at any rate this would appear to hold for right-eyed observers. There seems to be an inertia opposed to carrying rotary movement across the vertical axis. The general conclusion is drawn that the results of this research are in rough agreement with the constancy hypothesis of *Gestalt-theorie* in respect to the relation between physical and phenomenal pattern. The experience of apparent movement is partly controllable from the stimulus side, although there is an indefinitely large number of stimulus variables involved in the determination of visual movement. The "subjective" determinants are of paramount importance in such determination. These subjective factors are in especial need of further investigation.

Langfeld (**14**) has produced apparent visual movement by stimulating the two eyes in succession by the same stationary stimulus. Non-corresponding points of the two retinas were stimulated. The movement was, for the most part, the same as that derived by stimulating in succession neighboring points of one and the same retina. The form of stimulation was varied throughout the course of the sixteen experimental series in order that the movement experiences might thereby be more effectively analyzed. Certain of the phenomena were not conditioned by a single stimulus and some of the results do not have a direct bearing upon the problem of apparent movement. One series only was conducted in a dark room, the others being performed in a well lighted room. Five observers served under all the conditions, while two observers reported under the majority of conditions. Three forms of exposure apparatus were devised. These were the perpendicular exposure (P.E.) apparatus, the horizontal exposure (H.E.) apparatus, and the iris exposure (I.E.) apparatus. A diagram of the first named form of instrument is given. In the P.E. device there was a slight overlap of the two monocular presentations. The H.E. instrument did not permit of an exposure overlap. The discs or shutters of the P.E. and the H.E. devices were revolved by hand, and in the I.E. instrument the iris shutters were actuated by hand. In the P.E. device exposure

was from the upper point of the sighting holes to the bottom, and vice versa; in the H.E. apparatus exposure was from right to left, and vice versa. The I.E. set-up was used for eliminating the influences of both the horizontal and vertical movements of the shutters. Patterns such as the following were presented: a perpendicular black stripe, a semicircular black stripe in perpendicular position, two parallel and perpendicular black stripes, two parallel and perpendicular black stripes with a small black square half-way between them. The background was white in every case. In the final series, the dark room being used, a few observations were made with colored gelatin films placed over a perpendicular slit behind which there was a light. Experiment 5 may be given as a specific example of the research: A semicircular black stripe, placed in a perpendicular position, was the stimulus object. This object was presented in all of the three forms of apparatus. In general, the semicircle was observed to move back and forth as a whole. Occasionally the center moved in and out, the ends remaining stationary. One observer reported that the top frequently tended to turn, while the bottom was motionless. This observer found that by voluntarily fixating the center of the perpendicular diameter the semicircle moved as a whole; differences in fixation seemed to be the ground of differences in movement. Several observers reported that by controlling the fixation factor movement could be brought under control in various parts of the object, the rest of the curve remaining stationary.

The interval between stimulations influences the character of the movement. Although there was no accurate control of exposure speeds, it was evident that a variation in the speed from slow to fast resulted in succession, end movement, full movement, and simultaneity. Apparent movement of double images was investigated. Langfeld found that certain conditions resulted in "pure" movement. This "pure" movement was not the perception of the shutter movement. Paradoxically, this type of movement appeared to be the movement of an unseen object. Sometimes there was the experience of a moving object after the object had passed the exposure period, this object having a direction of movement opposite to that in which it usually took place when non-corresponding points of the retinas were stimulated in succession. Stimulation of one eye only by the object gave rise to movement, provided that the other eye was stimulated either before or afterward by the background. The attitude of the observer is a highly important factor in such a phenomenon as the reversal of movement of the stimulus object.

It appears that even though eye-movements may occur at times, nevertheless they are not the basic condition for the apparent movement produced by successive stimulation of the two eyes by the object. Stimulation of non-corresponding points of the retinas seems to be a necessary condition for full movement. However, the convergence factor must be taken into consideration as one of the conditions operative in the experience of full movement. Langfeld considers this research to possess a preliminary character only, and does not advance any theory of apparent movement based upon it. Rather, he aims to offer phenomenal results as such.

A minor study of visual movement by Vogt and Grant (19) is communicated by Langfeld. A simple form of gravity tachistoscope was employed; two circles of light were the stimulus objects, one being situated 5 cm. above the other. The objects were 6 mm. in diameter, being colored in various combinations by means of red, yellow, green, and blue filters. The stimuli were also presented without the filters, utilizing only the dim yellow light from the exposure box. The so-called Wertheimer optimal time interval of sixty sigma between the two exposures was adopted. Care was taken to bring about a partial control of eye-movements; this was accomplished by having the observer fixate the field through a pair of black tubes, each being one inch in diameter. Ten observers served in this experiment. Reports were obtained from two series of presentations. The total number of exposures for the group was 1,400. When the results from the two experimental series were intercorrelated a coefficient of 0.945 was obtained, the size of this coefficient indicating that the sampling was adequate. Also, intercorrelation between the reopts "streaks" and "bi-membral movement" yielded a coefficient of 0.89. Of the total number of sixteen reports of full movement only three were obtained in those instances where the stimulus objects differed in color. A summary of the protocols is given, from which it will be observed that the number of optimal movements is extremely small; this has significance in view of the fact that eye-movements were restricted. Incidental observations, dispensing with the tubes, indicate that the rôle of eye-movement in apparent movement can not be ignored. A consistent aspect of the movement phenomenon observed in this study was a streak between the two stimulus members, the color of the streak depending upon the stimulus color. As a rule, when the stimuli were of different colors, the streak was of one color only, resembling the color of one of the stimuli. Two streaks of different colors were sometimes

noted. This study contains certain data that are in harmony with the findings of Higginson concerning the effect of colored stimulus objects upon visual movement.

McConnell (**15**) investigated visual movement under simultaneous excitations with initial and terminal overlap. The research of Higginson on visual apprehension of movement under successive retinal excitations was the proximate source of the investigation in question. Exner, Fischer, and Wertheimer have emphasized the importance of temporal disjunction as a factor conditioning the arousal of apparent movement. But in Higginson's study it was shown that apparent movement could be produced with the simultaneous presence of both members of the stimulus pattern. In the present research the total exposition time was reduced and the degree of initial and terminal overlap was varied within a series of small steps. This was done in order to approximate as nearly as possible, under the condition of simultaneous presence of the stimulus members, the temporal variations that are usually utilized in the study of apparent movement under successive stimulation. The modified mirror tachistoscope used by Higginson in his study referred to above was used. Under the conditions of this investigation movement is easily and clearly perceived and the frequency of movement stands in a direct relation to the amount of temporal overlap. Both the main and the control series show that initial overlapping is more favorable to the appearance of movement than is terminal overlapping. A 100 sigma delay at initiation gave rise to movement in nearly every case, but 140 sigmas between the two endings were necessary in order to obtain the same result. The apprehension of the observer as to the order and character of the phenomenal members possesses as large an influence upon the reference and direction of the movement as the stimulus pattern. When there is initial overlapping, movement is generally apprehended in the direction of the delayed member. With terminal variation there was frequent failure to apprehend the members as being of simultaneous onset; here, movement was often referred to that stimulus member that came last phenomenally. Terminal variation was favorable to dual and intramembral movements. The protocols give evidence of large qualitative differences between observers, while there is a wide range of variability for one and the same observer.

An interesting case of apparent visual movement is described by Werner and Creuzer (**20**) which is considered by them as constituting strong evidence in support of the view that *Gestalten* arise not merely

within fixed and more or less restricted sensory modalities, but that normally they involve the psychophysical organism as a whole. During an investigation on stroboscopic movement it was incidentally discovered that a woman observer, Frl. P., was susceptible to what may be termed a "double-perception" (*Doppelanschauung*). Two Two distinctly different patterns were presented in succession in the stroboscopic manner. Two figures are given in the text, showing the kinds of pattern used. One of the experiments will now be described: A circle was first presented, this circle being situated on the lower left hand corner of a field. Secondly, there was presented a triangle, situated at the upper right hand corner of a field. The figures were white and the ground was black. With a sufficiently rapid rate of rotation of the apparatus, apparent movement took place. The movements differed for different observers; in particular, the movements differed as being bi- or tri-dimentional. For Frl. P., a "double-perception" of movement occurred more frequently than either bi- or tri-dimensional movement. This observer insisted that she observed two different movements in one and the same object at one and the same time, the two simultaneous movements being bi- and tri-dimensional: The circle would move toward the triangle, whereupon the triangle would move toward the circle; these movements were not complete. At the same time there occurred another movement of a tri-dimensional character, the circle and the triangle both rotating, in a manner (*gewissermassen*), about an invisible axis and upon the convex surface of a cylinder. It was noted that now the circle and now the triangle appeared in front of and then disappeared toward the rear of the cylinder. The observer expressed much surprise at the phenomena and called attention to the logical absurdity involved. Closer analysis revealed that the two simultaneous perceptions, really constituting a "double-perception," were not given in the same manner. In describing this perception the word seeing (*Sehen*) is used with two different meanings. The observer stated that she perceived *optically* the bi-dimensional movement only; the tri-dimensional movement, on the other hand, was "felt," was perceived in a mode other than visual. A simultaneity of these two logically contradictory phenomena remains uninterpretable unless it be postulated that the phenomena in question are conditioned through the "splitting" off from one another of two strata (*Schichtspaltung*), resulting in a specific optical level on the one hand and a "motorischempfindungsmässigen Schicht" on the other.

After the separation of levels has taken place, these levels function in an inadequate manner.

Volk (16) investigated the anorthoscopic distortion-images of Zöllner. This research was carried on in Schumann's laboratory and carries on the previous work of Hecht and Wenzel. Wenzel, for example, had utilized figures under the condition of slow motion. Volk, however, studied the various effects brought to bear by the two edges of a slit upon objects that were in rapid motion. A diagram and description of the exposure apparatus are given. Diagrams are presented showing the patterns used, together with the conformational changes at various stages. Two kinds of slits were used: straight and semicircular. Investigation was first of all directed to the phenomena involved in the appearance and the disappearance of a circular line behind a slit possessing straight edges. The speed of movement of the circular line and the width of the slit were subjected to variation. Record was made as to the consolidation, the flattening, and the movement phenomena occurring in the different segments of the stimulus object. In the second experimental series the moving object was a straight line inclined at an angle of 45 degrees to the slit, the edges of the slit being straight. It was found that a contour already present exerted an influence upon the consolidation of new contours. In order to check the results obtained through the use of the straight edges, Volk utilized a slit having semicircular edges and noted the changes that occurred when a rectangle approached such edges. The data obtained in the series involving the straight edged slit were checked up by the data obtained from the semicircular edges. That contour of a figure which was the first to vanish behind a curved edge conformed, became similar to, the form of the edge in question. Moreover, the contour that was the last to vanish evidenced conformational alterations that are to be attributed to the form of the edge behind which the figure came into view. The conditions were varied in respect to eye-fixation. Differences in the phenomena were noted to depend in part upon whether the observer fixated the field in a rigid manner or permitted the eye to follow the moving object.

Greb (5) has made a tachistoscopic investigation of certain phenomena occurring under the conditions presented by rapidly moving objects. The Schumann tachistoscope was used. When a moving vertical black line was presented under circumstances precluding eye-movement, the line was preceded by gray lines as well as followed by one or two gray parallel lines. When a colored stimulus

line was presented lines were observed to follow and to precede the objectively given line. Greb publishes a couple of tables showing the color phenomena occurring when the stimulus line was red-orange and when it was blue. Reference is made to earlier researches on after-sensations derived from moving and stationary objects under the condition of brief exposure. Greb relates his findings to the more recently obtained findings of Ehrenstein, Gehrcke, and Lau. Greb also used rotating discs, diagrams of which are given, on which were presented different sorts of patterns; these were observed both with and without the aid of the tachistoscope. It is thought probable by Greb that certain phenomenal increases in the figural aspect of a given field are due to after-sensations. The third division of the study is devoted to quantitative aspects, Tables IV to IX, inclusive, summing up the quantitative data.

Granit (4) has studied inhibition of the function of the so-called cones through the excitation of the so-called rods in the case of after-sensations of movement. The reviewer has used the word "so-called" in connection with the terms cones and rods on account of the existing dispute concerning the differentiation of the retinal elements. In the research at issue Greb determined the duration of after-sensations of seen movement and related this duration to the speed of, and visual angle subtended by, the stimulus. The stimulus objects used were black and white stripes on the rotating drum of a kymograph. The magnitude of the stimulus being constant, it was found that the duration of the after-sensations increased together with increase in the distance of the stimulus from the observer. Also, an increase in the speed of the stimulus object carried with it increase in duration of the after-sensation. It must be noted, however, that very small values for the visual angles occasioned a cutting down in the duration of the after-sensations. Granit determined the angular condition for maximal duration of the after-sensation: an angular value of about 2.3 to 3.8 degrees fulfills this condition. The theory is formulated that the rods situated in the periphery of the retina are responsible for the inhibition of the development of the central-cone after-sensation of motion. The further the stimulus extends toward the periphery the larger is the inhibitory effect of the rods. This view affords an interpretation of the fact that there is a brief duration of the after-sensations correlated with a short distance of the stimulus from the observer. Granit believes his hypothesis to be strongly supported by observations made under the condition of peripheral exposure of the stimulus, by means of which

method he believes that he has eliminated the supposed rod-cone antagonism.

Thelin (17) treats of the perception of visual movement conditioned by the movement of two small lights. Investigation is made of the factors of relative intensity, absolute intensity, position of the moving light, direction of movement, fixation, practice, knowledge, and individual differences. The chief significance of this research for the present review is its bearing on the topic of apparent movement. Reference is made to the laws of Korte and also to work done in the field of the autokinetic sensation. In the case of the autokinetic illusion the problem is chiefly that of absolute intensity, while in the case of the phi-phenomenon both absolute and relative intensity are involved. When the data obtained by Thelin are compared with those found in the field of the phi-phenomenon there are two respects in which differences apparently emerge. First, Korte found that in delta movement the more intense light was the more mobile. Thelin found that the weaker light was the more mobile. Second, in the phi-phenomenon "changes in absolute intensity are inseparable from changes in other factors in order to secure optimal movement." Thelin found that changes in absolute intensity exerted no appreciable influence upon perceived motion. These two orders of differences are discussed and the conclusion drawn that "there is complete accord between our results and the phi-phenomenon." By this statement it is not meant, however, that there are no differences between perceived physical movement and illusory movement; for Thelin found that the physical motion of the stimulating object is a positive factor in the perception of motion. The streaming phenomenon and pursuit movements of the eyes are here invoked as grounds for the interpretation of the differences between real and merely apparent movement.

Guilford and Dallenbach (6) have made a study of the autokinetic sensation. This investigation was undertaken for the purpose of determining the relation between eye-movements and the illusory movements in question. A summary of the facts which must be accounted for by any theory is given, together with a résumé of the historical background of the problem. Dallenbach was the observer. The apparatus and technique used were essentially those devised by Dodge, the chief modification being that a moving film of a panoramic camera was substituted for Dodge's falling plate device. The stimulus was a circular red dot of light 2.5 mm. in diameter, 170 cm. distant, and in the direct line of regard. In one series the left eye,

in a second series both eyes, were photographed. Eye-movement records are presented. It is concluded that eye-movements are not the basic conditions for the autokinetic sensation. The pathways of illusory movements give evidence of a striking uniformity, the typical path being circular and always extending along one of the diagonals of the visual field. The theory is tentatively advanced that streaming phenomena, often observed during the course of the research, constitute the ground of autokinetic movement. A high degree of significance is attached to the fact that the illusory movement patterns lay in the direction of the most frequent patterns of the streaming phenomena noted by Ferree and Edridge-Green, and that, when both eyes were involved, the movement pattern became irregular. It is still necessary, however, to determine the direction of the retinal currents for Dallenbach. The problem of spatial anchorage is considered. Minor oscillations in the paths of movement are accounted for in terms neither of eye-movements nor of streaming processes, but in those of pulse. The independent movement of two objects, observed by Carr, may well be interpreted in terms of streaming: the objects occupy retinal positions in two different streams. No difficulty is offered to the proposed theory by the fact that illusory movement takes place in the direction of eye-strain. Eye-strain may just as well be considered to be the result as the cause of movement; no critical experiment has as yet been performed, however, to decide this controversial point. The apparent rate of movement is significant for the streaming theory. Velocity, extent, direction, and duration of movement are to some extent under voluntary control. Investigation should be made in order to determine the nature of the effect brought to bear by previous positions of the eyes upon the character of the streaming processes. It is still necessary to analyze the current-patterns for a period of at least two minutes after the eyes are brought to fixation after previous orientations. Experiments should also be conducted to discover the rôles assumed by voluntary effort and strain exercised in different directions upon the direction of the currents of the retina. The theory awaits the outcome of these researches.

Ziehen (21) treats of the problems of *Punktschwanken*. Results of earlier researches appear to signify that the autokinetic phenomenon cannot be adequately interpreted in terms of involuntary eye-movements. Pronounced excursions were observed when luminous figures were used. It was found that movements in the downward direction were of relative infrequency. The illusion was not dissi-

pated by voluntary head-movements and eye-movements. The factors of accommodation, convergence, intensity of the stimulus, horizontal nystagmus, and memory-images were investigated. Ziehen had the opportunity to investigate the reactions of two cases of homonymous hemianopsia, and one case showing paralysis of the superior rectus, in respect to the autokinetic phenomenon. It is concluded by Ziehen, after modifying and checking up certain previous investigations, that involuntary eye-movements, at least extensive involuntary eye-movements, are not the foundation of the phenomenon.

Higginson (**9**) describes a simple and ingenious set-up for the class demonstration of apparent movement. By means of a rod device a pair of shadows is cast upon a white screen. By virtue of a lighting arrangement one of the shadows possesses an intensity so low that it is nearly or quite invisible when the other and stronger shadow is projected. First, the weaker shadow is thrown upon the screen. Then, by means of a knife-switch control, the stronger shadow is projected, whereupon the weaker shadow is observed to jump over to the position of the stronger shadow. When the switch is opened, the shadow jumps back. Several advantages are claimed for this set-up. These are the extreme simplicity of the set-up, the fact that the audience is convinced that there is no motion in the physical, but merely in the phenomenal sense; the size of the field of movement may be varied, the relative intensities of the shadows may be varied independently, the dimensions of the stimuli may be varied, movement may be obtained in a vertical as well as in a transverse direction. And, as an important point in the demonstration, in view of the history of apparent visual movement, it is clearly demonstrated that the time interval in such movement may be dispensed with.

Carmichael and Schlosberg (**2**) describe an apparatus for the demonstration of those visual illusions that are dependent upon what S. P. Thompson years ago called a "rinsing motion." Although the apparatus was independently devised, it was later found to be similar to a set-up described by Bowditch and Hall in 1880. However, the present device has certain advantages as compared with the older instrument. The rinsing motion consists of a circular movement of the stimulus pattern in which the pattern remains at a fixed distance from a center, and does not revolve about an axis situated within itself. Four views of the apparatus are given, together with detailed specifications. Illusions of the type presented by this set-up have not been adequately analyzed and the authors of the device are

engaged in an investigation of these illusions, paying particular attention to the influence brought to bear by various colors upon the character of the illusion. The apparatus appears to be as effective for analytical work as it is for purposes of demonstration.

Higginson (**10**) gives an account of the use made in the undergraduate laboratory of a modified form of the Dodge tachistoscope. This is thought to be the first time that the Dodge machine has been used in the general undergraduate laboratory course. By means of this instrument the beginner may most effectively study fundamental phenomena of vision. Apparent movement is included in the list of phenomena studied.

In (**8**) Higginson has formulated a note of a polemical tone. This note concerns what might appropriately be called the Dimmick-Higginson controversy concerning the problem of apparent visual movement. It goes back to certain criticisms made by Higginson in respect to Dimmick's well known study of the phi-phenomenon. Comments are made concerning technique, instruction, terminology, and interpretation. Dimmick is considered to have been in error when he regarded Higginson's investigation on apparent movement as confirmatory of his own and earlier research.

Koffka (**13**) gives a rather detailed critical evaluation of Higginson's investigation on the visual apprehension of movement under successive retinal excitations. The conclusion is reached that Higginson's position upon the problem of visual movement represents a compromise, "eine 'Synthese' der zwei Standpunkte, die man in Amerika structural and functional psychology nennt." The interpretations of Higginson are considered by Koffka to be inadequate in view of the experimental facts. The findings of Wertheimer and Korte are maintained to afford a superior view of the entire problem.

Troland (**18**) discusses some scientific and hygienic aspects of the natural color motion picture. Under the former aspect he considers "memory color" phenomena, which have been investigated by such workers as Hering and Jaensch and their students, and depth effects. Color impressions depend to a large extent upon the observer's knowledge of the objective situation which is supposed to be represented by the stimulus. This principle has been termed by Hering the "color constancy of objects." Troland gives illustrations of this principle. It is a well known fact that all the hues of the spectrum may be obtained by mixing three component color stimuli in various proportions, and that it is impossible to do so by using two components. It is accordingly a rather extraordinary fact

that the two-color process in the colored motion picture is capable of giving the impression of rendering all the colors of a scene. An analysis of this fact is made by Troland in terms both of "peripheral" and "central" factors, with emphasis upon the past experience of the observer. In respect to depth effects, Troland discusses the value of color as a secondary depth criterion, and points out the superior depth effects of the colored picture as compared with those of the ordinary black-white productions. In regard to the hygienic aspects of the colored motion picture, it is stated that eye-strain is less marked in this type of picture than in the ordinary motion picture where no colors are present. The modern color pictures are quite free from the older defects known as "bad register" and "fringing." Oculomotor strain is much reduced, while color contrast replaces to a large extent the so highly fatiguing brightness contrast of the ordinary black-white pictures.

Hulin (11) has made a study of apparent tactual movement. The attempt was made to discover compulsory conditions underlying tactual movement by using a succession of temporally and spatially discrete stimuli. A limiting range of values favorable to the arousal of tactual movement was sought. There is a distinct need at the present day for a determination of the relative importance of stimulus setting and attitude in this field of investigation. The first step to take is to discover whether there are compulsory conditions inherent in the stimulus complex. Hulin's research is devoted primarily to the analysis of the stimulus aspect. An historical sketch of apparent tactual movement is given, in which reference is made not merely to the researches on tactual movement but also to investigations on visual and auditory movement. The apparatus employed by Hulin was a modification of the Benussi Kinohapt. Two-point pressure was utilized. Each stimulus always had a duration of 150 sigmas. A temporal range of eight steps was used, this range extending from simultaneity to a positive interval of 300 sigmas between the ending of the first and the beginning of the second stimulus. Eight spatial separations, from 5 mm. to 150 mm., were adopted. Seven observers furnished a total of 13,500 judgments. A four-fold classification into "full," "end," "inner," and "bow" movement was obtained, the term optimal including these four species of movement. Of the total number of judgments, 29.7 per cent were comprised of movement experiences of some kind or other. A decided peak of frequency for the optimal experiences was found to occur at the minus 75 sigma interval, 63.7 per cent expressing the frequency in question.

The minus sign indicates a temporal overlap of the two stimuli. "Full" movement, making up 68.6 per cent of the optimal class, likewise manifested a marked peak of 49.6 per cent at the minus 75 sigma interval. The remaining kinds of movement vary in an indefinite manner over the whole temporal range. "Full" movement is uniformly distributed over the spatial range. The Korte space-time law, derived in the field of apparent visual movement, is not valid for apparent tactual movement so far as the data of Hulin's research are concerned. One definite quantitative relation only emerges from this investigation. This relation is that the minus 75 sigma interval is particularly favorable for apparent tactual movement.

From the qualitative aspect, the protocols show the persistent presence of four variable factors, namely, the peripheral factors of pressure spread and perseveration, and the associative ones of visual imagery and kinesthesis. Tactual movement is not a simple experience like the alleged phi-phenomenon of Wertheimer: bewilderment is a characteristic attribute of the movement experience. The variability of the reports is so marked that a determination of compulsory conditions cannot be arrived at from Hulin's study.

Kester (12) investigated apparent auditory movement. He studied this phenomenon in the course of a research that included both localization and movement phenomena. Two brief, sharply bounded, punctiform ("*punktförmiger*") auditory stimuli, in spatial and temporal separation, were used. Such experimental conditions are similar to the ones usually used in the study of apparent visual movement. Kester draws comparisons between his results and those obtained by Wertheimer and Korte in the field of apparent visual movement, and finds evidence supporting the doctrine of a pure "phi." He states that "kein 'Etwas' bewegt sich; die Zeit zwischen den beiden Knacken ist auch nicht mit Schallempfindung ausgefüllt; mit einem Wort, es bildet sich bei günstiger Pause zwischen den beiden Schällen das Wertheimersche 'reine Phi-Phänomen' heraus." Different types of auditory movement were found. For example, Kester reports a "leaping," "jumping" movement, that in the region of a temporal interval between the two clicks of the order of about 0.25 second passes over into a "swinging" movement. Often the subjects portrayed this "swinging" movement to themselves in terms of a large slowly swinging pendulum. Esthetic factors were discovered to be at times involved in this experience. One subject called the swinging movement "graziös." Investigation was made as to any possible alterations in the nature of the apparent auditory move-

ment when the intensities of the clicks were reduced, and when the intensities were increased. Examination was made as to the relations between the successive and the optimal and the simultaneous stages.

The study by Bennett (1), from the physics laboratory of Union College, has interest for the present review on account of its bearing on the problem of apparent auditory movement. A phenomenon is here reported that is similar, as Bennett states, to the binaural effect investigated by Hornbostel and Wertheimer. The experiment under discussion, in which the minimum perceptible time interval was determined, grew out of a physical problem in which the task was to discover whether two pulses in different electrical circuits occurred simultaneously. The time interval between pulses could be varied between the limits of 0.0025 second and zero. Coincidence or non-coincidence of pulses was estimated by means of the ears. The successive pairs of pulses were presented, for the larger part, at an interval of two seconds between pairs. Such brief time intervals between pulses were used that the two pulses could not be perceived as discrete: a single pulse was observed, traveling from right to left or from left to right. The direction of the apparent auditory movement depended upon which ear was the first one to be stimulated. Eleven observers served in this investigation. Fifty per cent correct is taken as the limit of the observer's ability to determine the direction of the movement. Data distributions in graph form are given for certain phases of the study. One observer was able to attain 82 per cent of correct judgments at the low time interval of six and one-half millionths of a second. The general conclusions are drawn that every observer was able to distinguish direction of movement with certainty at one one-thousandth second, and that the average limit set for all the observers was one ten-thousandth second " or less."

Halverson (7), investigating the upper limit of auditory localization, found that with phase-changes tones possessing high frequencies move over a more restricted field than do tones of low frequencies. This decrease in the amount of movement is at first rapid and then becomes less rapid for the very high frequencies.

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SPECIAL REVIEWS

PARSONS, J. H., *An Introduction to the Theory of Perception*. Cambridge University Press, 1927. Pp. viii + 254.

Parsons' theory of perception is based on the doctrine of "Emergent Evolution": "Something new has occurred, which could not have been foretold, because it is not interpretable in terms of resultant effects calculable by algebraical summation. . . . At a certain stage in evolution life emerged; at a later stage consciousness emerged. . . . The distinguishing feature of the conscious-organic phase is the presence of 'effective consciousness,' *i.e.*, consciousness which enables the animal to guide its actions in the light of previous experience" (p. 2). "It would also appear that we must accept 'with natural piety' that, when some new kind of relatedness is supervenient, the course of events at a lower level *may* be altered" (p. 3). It is not precisely stated that the course *is* altered, and subsequent discussion, while touching this point again and again, develops no clear conception as to *how* it is altered. Controlled activity is frankly accepted as teleological, though not necessarily involving a "mental forecast of the end" (p. 17). "If we regard all consciousness . . . as based on a cortical mechanism, then any pre-perception in the first instinctive act is due to an inherited cortical constitution, whilst the added pre-perception of the second and subsequent acts, due to experience, are caused by 'backstroke' from the cortex" (p. 28). In the author's conception of a "pure" instinct "only the primary impulses should be taken into consideration. They give rise to (1) a cognitive element, which is the perception of the specific situation, and (2) an affective element, which is the synthesis of the affective elements of the afferent impulses and manifests itself as emotional tone" (p. 30). Before an instinctive act occurs there is an unfocussed affective state known as coenesthesis. "Upon this gray surface the emotion impinges like a splash of color" (p. 31). "The proto-affective state is enriched and reinforced by backstroke: the cognition, associative memory, is enriched by backstroke and becomes intelligent" (p. 35).

Having posited teleology, the growth of meaning accompanies the development of teleological control, "from little more than a mechanical response" (p. 26). As for the part played by consciousness in the development of this control, "we are dealing with plastic and ever-

varying elements of sensation and so on; and these entities, belonging to apparently quite incongruous types, differing utterly from each other in their qualities, are synthesized or integrated into new units of consciousness in a manner which physical and chemical laws fail entirely to explain" (p. 39). A conclusion is therefore reached that the fundamental utility of consciousness is "for the very purpose of synthesizing and integrating the apparently incongruous elements of which consciousness is made up—extero- and intero-ceptive impulses and so on" (p. 40). This somewhat confusing statement is really intended to embrace the coördination of processes in the nervous system which are classified under two heads: "plurireceptive summation and interference" (p. 40).

It is remarkable that the author should find support for this view of perceptual integration as summation and interference from the writings of Koffka. Koffka's example of a child's early response to the facial expression of its mother—a very complex visual impression—is a case in point. The child "responds to this complex by appropriate behaviour," writes Parsons, "simply because through countless preceding generations its ancestors have responded to similar and even less differentiated complexes" (p. 42). Had Parsons read carefully the book to which he here refers he would have found a quite different interpretation of the facts, and one more nearly in harmony with his general postulates. As it stands, the author's theory remains vague and obscure, because he retains sensations as "objects presented to the subject" (p. 42), while at the same time he insists that a percept "is not a mere collocation or summation of sensations. These have been integrated into patterns, in which the whole is greater than the sum of its parts; something new has emerged in consciousness" (p. 43).

How this integration takes place we are not told; but scattered throughout the book are various references to the function of *attention* which indicate the uncertain foundations upon which the author seeks to build his theory. First we are told that "awareness is focussed upon those features of the pattern which are of greatest biological significance, and becomes attention. . . . At higher levels . . . attention becomes interest" (p. 44). Later on this question is asked: "May we not regard attention as in some manner a sensitizer of the formative zone, whereby the processes going on in the cells of this region are so modified and adapted that they modify and correlate the congeries of impulses infringing upon them, moulding them into a physiological pattern which is the substratum of the psychological

pattern"? (p. 55). While this question is not answered explicitly, we are informed on page 146 that "physiologists have been forced to bend the knee to psychologists, who have invoked 'attention' as the *deus ex machina*"; and on page 156 appears the statement: "We have seen already that attention modifies and controls the activities of the formative zone."

Although the postulate of "Emergent Evolution" seems to give play to a controlling factor, the nature of which being unknown is termed "psychological," the author is apparently not without hope that eventually this factor may be brought within the range of physiological facts. The following passages at the end of the book (p. 245) bear upon this point: "Many of the phenomena included under the comprehensive term contrast cannot at present be explained on purely physiological grounds. It has already been pointed out that the perceptual pattern is a psychological whole of a nature different from the whole which is the mathematical sum of its parts. It is a new formation which emerges, but, like many of the examples of emergent evolution already cited, it does not follow that it will not ultimately become explicable in terms of a lower order, in this case physiological terms, with the greater advance of knowledge. Incidentally, one may point out that our knowledge of the parts of the perceptual pattern is very incomplete. Certain parts can be analyzed from it and are revealed as sensations of manifold modality and quality acting together to the common end. And since we have never experienced an isolated sensation, and know little of plurireceptive summation, etc., except that they are experimentally observed facts, it would be premature to dogmatically infer that they transcend known physical and physiological laws. And further, Frank Allen's experiments [on visual 'fatigue'] have shown that there is more in physiological induction than had been dreamt of in our philosophy. They have shown that the reciprocal activities are much more complex than had previously been discovered; and they have afforded a physiological explanation of many facts which were formerly obscure. It is by no means improbable that they lie at the roots of many of the 'back-stroke' influences of higher centres, of which the modifying and transforming effects of attention are the most striking."

The hope which is thus expressed of eventually securing a physiological explanation of perceptual formation would have a better logical foundation if the author had been able to detect the incongruity of providing any means other than those of a *deus ex machina* for securing the formation of entities which exist independently, each

in its own right. The possibility of formation as a fundamental instead of an accessory principle does not seem to have occurred to Parsons, despite the fact that he frequently refers to the writings of Koffka, Köhler, and Wertheimer. This failure to consider a theory of perception which is both well known and well supported by experimental results is the chief defect in an otherwise interesting and suggestive book.

It would, however, be unfair to omit the statement that the body of Parsons' book is concerned, not with the theory of perception, but with Head's protopathic (called *dyscritic*) and epicritic systems of neurological development, and with the bearing of this differentiation upon perceptual responses, chiefly those of vision.

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